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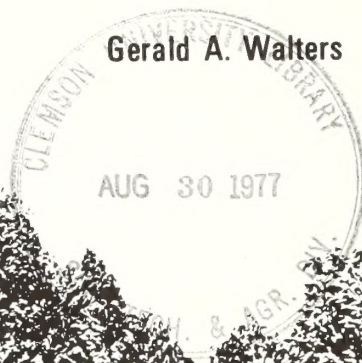
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PACIFIC SOUTHWEST Forest and Range Experiment Station

Species Adaptability Trials For Man-made Forests In Hawaii

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CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Tree Introductions in Hawaii	3
Methods	5
Species Selection and Planting Practices	5
Planting Site Selection and Experimental Design	5
Observations, Measurements, and Performance Assessment	6
Site Conditions and Species Performance	6
Hawaii Island	6
Maui Island	10
Molokai Island	13
Oahu Island	15
Kauai Island	18
Conclusions—A Look into the Future	21
Literature Cited	22
Appendix	24

SUMMARY

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In Hawaii very few of the native tree species are of value for timber production. Over the past 100 years, introduced species from the Pacific Basin proved more useful for reforestation. Introduced species were usually easier to propagate in the nurseries, and many performed better than the native species when outplanted. Before 1960 the major emphasis was on establishment of protection forests. These forests replaced native stands decimated for fuelwood, and served to protect denuded watersheds and to cover erosion scars. Interest in the establishment of new forests for timber production developed about 1960. Species adaptability trials were begun, with the aim of identifying economically valuable timber trees adapted to local growing conditions, and at the same time eliminating useless candidate species as quickly as possible. These trials were made on a wide range of sites.

Tree seeds were obtained from cooperators in 38 countries in the tropics, subtropics, and warm temperate zone. Seeds from 144 provenances, representing 90 species, were sown in beds or containers; the seedlings were later outplanted as bare-root or potted stock.

A total of 16 planting sites were established on the islands of Hawaii, Maui, Molokai, Oahu and Kauai during the 1960's. On these sites elevation ranged from near sea level to 6360 feet (1940 m); rainfall ranged from less than 20 inches to more than 200 inches (500 to 5000 mm); and soils ranged from thin mucks overlying lava rock to deep, highly leached latosols.

The experimental plantings were laid out in a randomized block design, usually with five replications and 6-tree row plots for each species. When a shortage of seedlings occurred, two or more species were sometimes included in a row plot. Survival, growth measurements, vigor, and stem quality of the trees were recorded at the end of the first, third, and fifth years after outplanting.

Ten conifers and thirty-two hardwood species were rated as having promise for timber production,

craftwood, amenity plantings, or for protection forests. Fourteen of these species are native to Australia; and ten are eucalypts. On some of our test sites, several species grew well, at other sites few or none of the species proved well adapted. The performance of most of the high quality hardwood species tested was disappointing.

The eucalypts outperformed other species, especially on the low quality sites. *Eucalyptus camaldulensis* lived up to its worldwide reputation as the eucalypt capable of growing well on a wide range of moisture regimes and soils. Two Southern Hemisphere conifers initially promising are *Araucaria angustifolia* from Brazil and *Callitris endlicheri* from Australia. *Pinus kesiya* and *P. engelmannii* were among the six true pines considered promising. *Swietenia mahagoni*, *S. macrophylla* and *Cedrela odorata* showed sufficient promise to justify further investigations. This was also true for *Cordia subcordata* and *Thespesia populnea*, two species useful as craftwood and introduced by the early Polynesians.

Many of the promising species exceeded our minimum performance standard, which is a combination of 60 percent survival, height growth of 3 feet (1 m) per year, and 70 percent good vigor. These criteria were lowered for species planted on low rainfall sites (under 40 inches or 1000 mm per year). Very few trees died from disease or insect attack. Most failures and unsatisfactory performances relate to harsh site conditions, such as low soil fertility, droughts, desiccating winds, and weed competition.

The species rated promising for timber production will be tested more intensively in pilot-scale plantings. Several of the eucalypts deserve special attention for use in short-rotation "energy plantations"—that is, as a substitute for fuel oil in generating electricity. This is presently feasible on the islands of Hawaii and Maui. Growth of these species suggests that under intensive management, fuelwood production on short rotations would become more profitable as oil prices rise.

Man's activities have adversely altered growing conditions for native forest trees on many thousands of acres in Hawaii. These lands can again become productive if they are reforested. But reforestation success on a particular site depends to a large extent on the choice of tree species. Foresters have long been faced with this problem; in 1665 John Evelyn stated it in his classic work, *Silva*: "First it will be requisite to agree upon the species: as to what trees are likely to be of greatest use, and the fittest to be cultivated and then to consider how planting may be best effected."

Species adaptability trials, which basically are short-term elimination trials, serve to identify tree species deserving further attention for planting on these modified habitats.

Although native Hawaiian trees collectively serve as valuable protection forests, only a few species have proven satisfactory for either reforestation programs or urban beautification. Hawaiian species have not shown superior adaptive characteristics on sites radically altered by erosion, fire, cultivation, or other destructive agents. On such areas trees from other countries often prove to be more useful for the establishment and development of man-made forests. These forests will help to meet the increasing demand for forest products and at the same time will provide other benefits such as recreational areas.

Only coordinated, long-term studies can determine the suitability of exotic species to Hawaii's conditions. The initial step is to screen many species in adaptability trials. Those which show promise are

then tested in larger scale pilot planting trials. This paper presents the results of adaptability trials established by the U.S. Forest Service in cooperation with the Hawaii Division of Forestry. The performance of 90 hardwood and coniferous species from 38 countries in the tropical, subtropical, and warm temperate zones of the world was appraised.

Our primary objective on most sites was to evaluate the performance of timber trees, especially fast growing species recognized in the world market for their high quality. Considerable research emphasis was therefore directed toward screening high-quality hardwoods—for example, members of the mahogany family (*Meliaceae*). Species adapted to adverse sites, such as dry and eroding lands, were also sought for use in the establishment of protection forests. Later, for selected sites, the scope of the study was broadened to assess the value of species for craftwood, amenity plantings, and Christmas tree production.

These field trials have identified 10 coniferous species and 32 hardwood species that merit more intensive trials for timber production or other uses. This paper reports results of the trials according to site, identifying the species as promising, unsatisfactory, or failures, and tabulating the significant characteristics of the species performance on the individual site. A general index gives seed source and performance rating for each species planted; for promising species, site characteristics (island, elevation, rainfall) and recommended uses are tabulated. A table of relevant soil classification equivalents is also provided.

TREE INTRODUCTIONS IN HAWAII

Hawaii is a unique place for growing trees. A chain of eight major volcanic islands, it is situated in the North Pacific Ocean, just south of the Tropic of Cancer (*fig. 1*). The islands lie between 18°54' and 22°14' north latitude and between 154°48' and 160°15' west longitude. They are separated from the

United States mainland by 2400 miles (3860 km).

There are two seasons. Summer is the season of northeast trade winds. Winter is a period when the trades are occasionally interrupted by southerly and westerly winds, bringing increased cloudiness, humidity, and storms. These storms bring Hawaii its heavy-

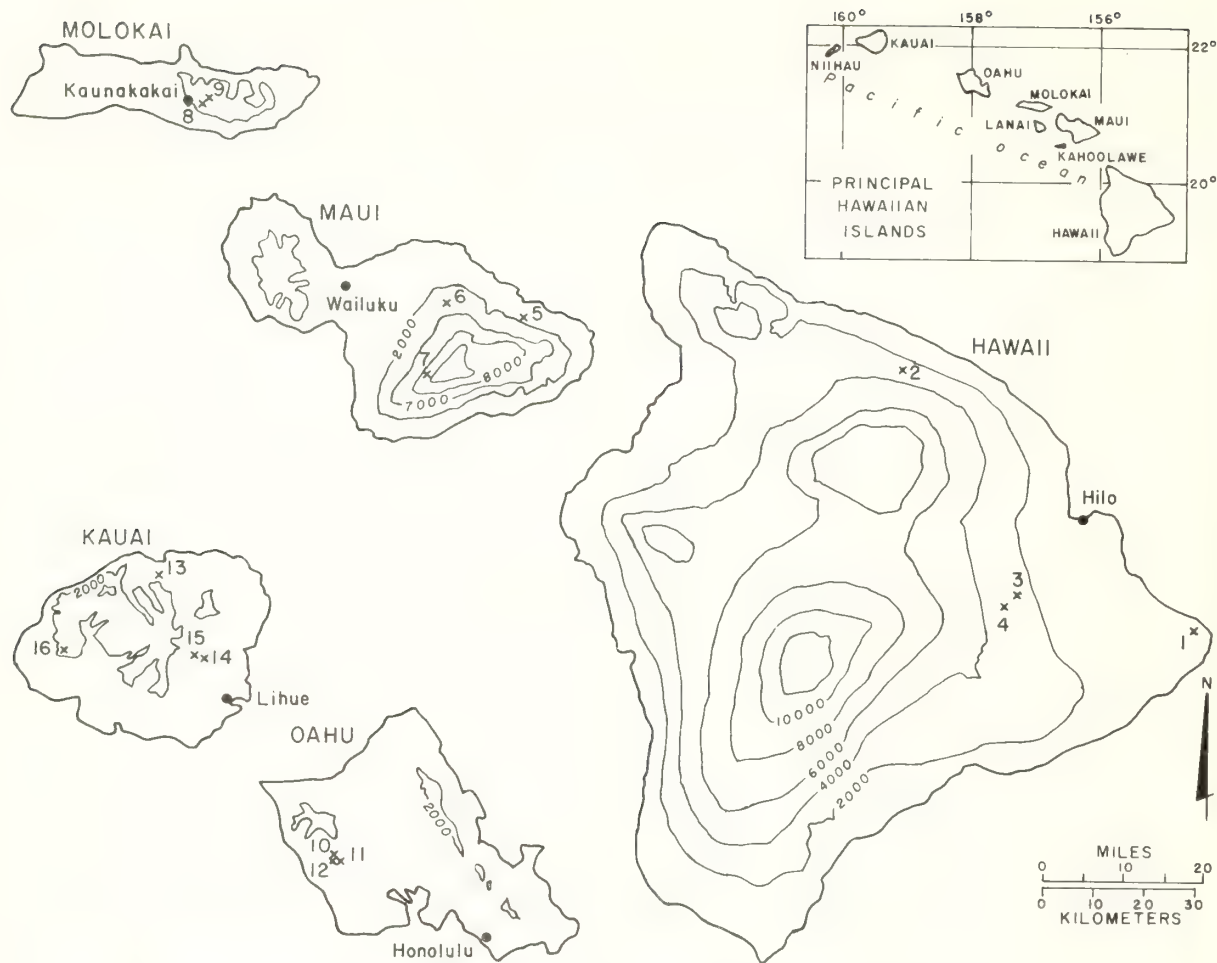


Figure 1—Species adaptability trials were made on the numbered sites shown here, on five of the Hawaiian islands. These trials serve to identify tree species deserving further attention for planting.

est rains, and are usually the only source of rainfall for the dry, leeward areas. Severe, extended droughts may occur in these areas when the winter storms fail to materialize (Price 1973).

Hawaii's mountains influence all aspects of its climate. The northeast trade winds bring rain to the windward areas most of the year. On the higher mountains annual rainfall may range from 100 to over 450 inches (2540 to 11,400 mm). Generally, above 3000 feet (914 m) on the windward slopes, the average annual rainfall begins to decrease rapidly—slopes above 7000 feet (2134 m) receive less than 30 inches (760 mm). Temperatures decrease as elevation increases, by about 3° F per 1000 feet (1° per 100 m). Near sea level, average temperatures range from

about 75° F (24° C) in March to 80° F (27° C) in September. In most areas the daily range exceeds the seasonal range by about 3° F (1.7° C) (Price 1973). Cloud cover, which is almost a daily occurrence over some areas at mid-elevations, greatly influences temperature, radiation, and humidity, and therefore plant growth.

The purposeful introduction of trees into Hawaii began with the arrival of the first Polynesians over 1200 years ago. They brought the kukui or candle-nut-tree (*Aleurites moluccana* [L.] Willd.), now Hawaii's state tree, milo (*Thespesia populnea* [L.] Soland.), kou (*Cordia subcordata* Lam.), and many others. Like the first Polynesians, later immigrants to Hawaii brought trees that were important to them.

Many of these introductions, which now total in the hundreds (Nelson 1965; St. John 1973), have become so familiar that they seem almost a part of the natural flora. Many of the ornamental trees brought here are also appreciated elsewhere in the tropics for landscaping, shade, food production, and other uses.

One century ago, Clarke (1875), remarking on the decadence of Hawaiian forests, suggested certain exotic and native species for renewing the beauty of the islands. The introduction of trees for reforestation began around 1870, during the reign of King Kalakaua (Lubker 1886; Walker 1887). By this time many of the native forests had been decimated by timber and firewood cutting, fires, and clearing for farming and ranching. Insects, disease, feral animals, and aggressive introduced plants contributed to the decline of the native forests. Initially, native species were tried for reforestation. Most of these plantings failed, however, probably because the environment under which these species once flourished had deteriorated. Needed were trees that were easier to propagate and could survive and grow under harsh conditions. Attention turned to exotic species, principally *Eucalyptus* and *Casuarina* species from Australia.

From about 1903 to 1960, the Hawaii Division of Forestry screened hundreds of tree species for their adaptability to local conditions (Bryan 1947; Crosby and Hosaka 1955; Hosmer 1912; Kraebel 1922; and Margolin 1911). The value of these trees, selected principally for watershed protection, was continuously reappraised, and some species became more favored than others. Unfortunately, planting records were not always kept, or have been lost.

In about 1960, the State began to emphasize reforestation activities aimed at increasing timber yields on the forest reserves (Hawaii 1962). Many of the earlier tree plantings had shown that timber trees could be successfully grown in Hawaii, and that growth rates on good sites far exceeded those obtained in temperate zone areas (Carlson and Bryan 1959; Pickford 1962; Pickford and LeBarron 1960). By 1973 only 38 thousand (4 percent) of Hawaii's 938 thousand acres of commercial forests were planted, yet these forests contain about 40 percent of the sawtimber growing on these lands (Nelson 1973). The field trials described in this paper were established for the purpose of identifying useful timber species adapted to the many diverse sites throughout the State.

METHODS

Species Selection and Planting Practices

Species were selected by

- Screening the literature to identify the species most likely to succeed.
- Evaluating species performance in older local trials.
- Seeking suggestions from tropical foresters.

Tree seeds were obtained from 38 countries in the tropical, subtropical, and warm temperate zones. A total of 144 provenances, representing 90 species, were obtained and outplanted. These are listed, with the sites in Hawaii where they were planted, in the appendix (*table 17*). Information on location, elevation, rainfall, and stand and site conditions of the seed source was usually partially or wholly lacking. Our alternative was to rely on available literature, which provided useful information for many but not all species. Countries in the British Commonwealth were the most informative sources of literature on species introductions.

Seeds were sown in flats, cans, plastic bags, and

nursery beds at forest nurseries throughout the State. Seedlings were treated with fertilizers, fungicides, and insecticides as required. Both bare-root and potted stock were outplanted. In the field, site preparation consisted of removing all competing vegetation. Spacing was 5 feet (1.5 m) within rows, 8 feet (2.4 m) between rows, and 10 feet (3.0 m) between blocks. Brush and grasses were controlled by periodic chipping, and occasionally weedicides were applied.

Planting Site Selection and Experimental Design

Sixteen sites, representing extremely diverse site conditions throughout the State, were selected for these species adaptability trials. Most of these areas were within or adjacent to areas that had been planted with trees in previous years. In general, we chose sites typical of large areas in need of productive

forest cover. Many of these areas were known to present difficult establishment problems, and none resemble the romantic vision of a lush tropical island. Elevations range from 100 feet to 6360 feet (30 to 1939 m); annual rainfall varies from about 20 inches to over 200 inches (500 to 5080 mm); and soils vary from old, deep, and highly leached to lava rock overlaid by shallow muck.

The soils, identified by series names, and placed in the U.S. Soil Taxonomy, are listed in the appendix (table 18). This system is also correlated with the older U.S. Classification System of 1938, the FAO/UNESCO Legend, and the French Soil Classification (Beinroth and others 1974). This provides a way to compare soils of Hawaii with those of other tropical regions.

The experimental design consisted of five replicated blocks, each with 10 or more randomized row plots. Each plot usually consisted of six trees from one seed lot, for a total of 30 seedlings tested. Occasionally, as few as five seedlings per seed lot were represented (1 tree per lot). Ten or more species were planted at each experimental area.

Different provenances of a species were often grown in different nurseries at different times, and planted in the field under varying conditions. Similarly, seedlings from the same seed lot were often raised at different nurseries and planted at different sites. For these reasons each planting of a given provenance at a given site is considered a separate test. No statistical comparisons were made between species or provenances.

Observations, Measurements, and Performance Assessment

Observations and measurements were usually recorded at the conclusion of the first, third, and fifth years. The trees were examined for survival, total height, vigor, and stem form. Tree vigor was rated as either good or poor, based upon crown development and general condition.

Survival, height growth, and vigor were considered in judging the performance of a species on a specific site. Species were rated as "promising," "unsatisfactory," or "failures." Performance standards to distinguish a species as promising were usually based upon a composite rating of survival, annual height growth, and vigor. Minimum performance for a species to be rated promising, on areas receiving over 40 inches (1000 mm) of rainfall, was survival of 60 percent, average annual height growth of 3 feet (1 m), and good vigor of 70 percent of the trees. On dry sites (rainfall under 40 inches), an annual growth of 2 feet (0.6 m) was considered acceptable. However, our criteria allowed a species to be rated promising although not meeting the above standards for one or two factors, if it excelled for another. Stem quality assessments were used only to judge the sawtimber potential of a species.

A species was rated "unsatisfactory" if survival was low and growth rate and/or vigor were low. A species was judged a "failure" if survival was very low, growth was slow, and a high percentage of the trees showed low vigor.

SITE CONDITIONS AND SPECIES PERFORMANCE

Hawaii Island

SITE 1

The planting site is in the Nanawale Forest Reserve, about 0.7 mile (1.1 km) northwest of Cape Kumukahi. Latitude is 19° 32' north and longitude is 154° 51' west. Elevation is 100 feet (30 m); aspect is east, with slopes of from 1 to 15 percent. The average annual rainfall is about 100 inches (2500 mm), with an average of 5 inches (125 mm) or more, usually occurring each month. Dry periods of a month or longer may occur at any time during the year.

The soil is Malama extremely stony muck, a thin organic soil overlying fragmented aa lava. This soil is well drained; permeability is rapid, and runoff is very slow. The soil is strongly acid (pH 5.3). Tree roots

may extend to a depth of 24 inches (60 cm) or more into cracks in the lava (USDA 1972). During site preparation the stony muck became mixed with cinders laid down in the 1960 eruption.

Objective—Trials on this site were established to identify tree species useful for timber production. However, recently, adjacent holdings in private ownership have been rezoned urban. Now species are being appraised for their amenity values as well as their timber potential.

Results and Recommendations—Seventeen species were tested, of which nine were rated as promising for both timber and ornamental purposes, after 5 years (table 1). Most of the promising species had over 83 percent survival and an average annual growth rate of more than 4 feet (1.2 m). The most outstanding species was *Albizia falcataria*, which had 100 per-

Table 1—Performance of species and provenances planted at Site 1, Nanawale Forest Reserve, Hawaii Island, evaluated after 5 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	Feet			Percent
PROMISING						
<i>Albizia falcataria</i> (Hawaii) 203	18	¹ 100	30	11 to 41	14.3	94
<i>Araucaria columnaris</i> (Hawaii) 239	18	83	14	4 to 24	2.8	100
<i>Eucalyptus citriodora</i> ² (Hawaii) 246	41	² 38	43	24 to 56	6.7	88
<i>Flindersia brayleyana</i> (Australia) 200	18	83	23	9 to 32	4.6	100
(Hawaii) 219	18	61	18	1 to 26	3.6	90
<i>Hibiscus elatus</i> (Puerto Rico) 104	18	94	16	6 to 49	3.2	88
<i>Pithecellobium saman</i> (Hawaii) 237	18	² 94	21	1 to 30	4.2	88
<i>Pterocarpus echinatus</i> (Philippine I.) 5	18	100	22	7 to 35	4.4	61
<i>Swietenia mahagoni</i> (Hawaii) 221	18	94	18	6 to 29	3.6	41
(Hawaii) 258	44	² 95	27	5 to 40	4.2	62
<i>Tectona grandis</i> (Malaya) 164	9	100	23	19 to 30	4.6	100
UNSATISFACTORY						
<i>Chlorophora excelsa</i> (Nigeria) 67	18	94	12	6 to 27	2.4	41
<i>Serialbizzia acle</i> (Philippine I.) 102	9	78	8	3 to 12	1.6	14
<i>Sindora supa</i> (Philippine I.) 43	18	56	7	3 to 11	1.4	40
<i>Terminalia superba</i> (Ghana) 179	18	33	13	3 to 20	2.6	33

FAILURES: *Entandrophragma utile* 186; *Mansonia altissima* 254; *Pahudia rhomboidea* 44; *Pericopsis elata* 255.

¹ Age 2.1 years.

² Age 6.4 years, seed sown in prepared spots.

cent survival and averaged 30 feet (9.1 m) in height at age 2.1 years. These trees were removed because they were overtopping adjacent species. *Flindersia brayleyana* was represented by two provenances—one from Australia and the other from Hawaii. Both sources proved satisfactory. *Swietenia mahagoni* trees which developed from seeds sown in prepared seed spots outgrew planted stock. Only 38 percent of the *Eucalyptus citriodora* trees planted survived. The high mortality was caused by an unidentified watermold (*Pithium* sp.) which appeared during an extended wet period. No trees of this species died after the third year.

The priority now is to establish these nine promising species in pilot scale plantings, where they can be further evaluated as they develop under closed stand conditions.

SITE 2

The planting site is in the Kalopa Section, Hamakua Forest Reserve, located approximately 4 miles (6 km) southwest of Honokaa town. Latitude is 20° 02'

north and longitude is 155° 26' west. The elevation is 2100 feet (640 m); aspect is northeast, with slopes of from 6 to 20 percent. Annual rainfall has averaged about 110 inches (2800 mm) during the last 10 years.¹ Rainfall is usually well distributed throughout the year, but extended droughts occur every few years.

The soil is Honokaa silty clay loam, formed in volcanic ash. It is well drained; permeability is rapid, and runoff is slow. This soil is friable when moist, but sticky and plastic when wet, and it dehydrates irreversibly into fine gravel-size aggregates. Roots can penetrate to depths of 5 feet (1.5 m) or more (USDA 1973). This soil is strongly acid to medium acid (pH 5.3 to 5.7). Low soil fertility limits growth of some tree species on this site.

Objective—Trials were made to identify tree species useful for timber production and for amenity plantings.

Results and Recommendations—Thirty-seven species were tested, with five represented by two or

¹ Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Honolulu, Hawaii.

more provenances (table 2). Eight species were rated as promising for timber production, and should be included in pilot scale plantings. These include the two provenances of *Araucaria angustifolia*; *A. columnaris*; *Cedrela odorata*; *Chukrasia tabularis*; *Eucalyptus deglupta*; *Flindersia brayleyana*; and *Hibiscus elatus*. The Hawaiian provenance of *Flindersia brayleyana* grew over twice as fast as the Australian provenance. *Grevillea robusta*, known to be well adapted to the site (Pickford and LeBarron 1960;

Nelson and Honda 1966) grew well, but was very limby. This species is deserving of intensive silvicultural research to improve its form.

Fraxinus uhdei and *Liquidambar formosana*, the latter represented by two provenances, grew vigorously, but form was poor. Further plantings for timber production are not recommended for either species until progeny of trees of superior form are tested.

Table 2—Performance of species and provenances planted at Site 2, Hamakua Forest Reserve, Hawaii Island

Species, seed source, and Hawaii seed lot number	Trees planted	Age	Survival	Height			Good vigor
				Average	Range	Annual growth	
		Years	Percent	Feet			Percent
PROMISING							
<i>Araucaria angustifolia</i> (Argentina) 300	10	4.4	80	10	8 to 12	2.3	100
(Brazil) 364	6	5.9	83	21	19 to 23	3.6	100
<i>Araucaria columnaris</i> (Hawaii) 398	10	5.3	90	12	8 to 16	2.3	100
<i>Cedrela odorata</i> (Mexico) 144	30	5.9	100	17	2 to 32	2.9	66
<i>Chukrasia tabularis</i> (India) 331	30	5.9	100	21	10 to 32	3.6	70
<i>Eucalyptus deglupta</i> (Australia) 227	30	5.0	97	27	5 to 45	5.4	89
<i>Flindersia brayleyana</i> (Hawaii) 219	30	5.0	100	11	2 to 23	2.2	90
<i>Grevillea robusta</i> (Hawaii) 225	30	5.0	97	16	7 to 27	3.2	89
<i>Hibiscus elatus</i> (Puerto Rico) 104	30	5.0	87	11	4 to 24	2.2	84
<i>Liquidambar formosana</i> (Taiwan) 324	30	5.3	100	17	13 to 21	3.2	100
(Hong Kong) 325	30	5.9	100	19	13 to 25	3.2	100
<i>Tabebuia heterophylla</i> (Puerto Rico) 271	30	5.3	80	12	5 to 17	2.3	91
UNSATISFACTORY							
<i>Agathis australis</i> (New Zealand) 213	30	5.3	73	4	3 to 6	0.8	81
<i>Cardwellia sublimis</i> (Australia) 401	30	5.9	53	12	2 to 24	2.0	81
<i>Castanospermum australe</i> (Australia) 285	30	5.3	77	7	1 to 17	1.3	100
<i>Cedrela odorata</i> (Mexico) 143	30	5.0	90	7	2 to 16	1.4	62
(Trinidad, W.I.) 208	30	5.3	70	11	1 to 25	2.1	95
<i>Cordia alliodora</i> (Costa Rica) 177	30	5.3	93	7	1 to 17	1.3	60
(Venezuela) 393	30	5.9	100	13	4 to 25	2.2	53
(Fiji) 395	30	5.9	100	9	1 to 24	1.5	33
(Costa Rica) 264	30	5.3	100	5	1 to 13	0.9	50
<i>Flindersia brayleyana</i> (Australia) 200	30	4.7	90	6	1 to 18	1.3	74
<i>Fraxinus uhdei</i> (California) 15	30	5.0	100	22	9 to 32	4.4	90
<i>Juglans australis</i> (Bolivia) 400	5	5.9	100	11	4 to 16	1.7	40
<i>Juglans boliviana</i> (Costa Rica) 338	30	5.3	63	7	1 to 21	1.3	73
<i>Maesopsis eminii</i> (Kenya) 293	9	5.3	89	8	1 to 21	1.5	67
<i>Phoebe porosa</i> (Brazil) 412	15	5.9	100	9	4 to 13	1.5	26
<i>Pterocarpus echinatus</i> (Philippine I.) 5	30	4.4	100	8	3 to 15	1.8	40
<i>Swietenia macrophylla</i> (British Honduras) 336	30	5.9	77	5	2 to 9	0.8	21
<i>Tectona grandis</i> (Australia) 164	10	5.3	100	3	1 to 7	0.6	30
<i>Terminalia ivorensis</i> (Nigeria) 204	30	5.9	100	6	1 to 14	1.0	3

FAILURES

Amburana sp. 89
Berrya cordifolia 314
Brosimum sp. 383
Chlorophora excelsa 67
Gyrocarpus americanus 328

Mansonia altissima 254
Pahudia rhomboidea 44
Pericopsis elata 255
Roseodendron donnell-smithii 272
Sindora supa 43

Taxodium distichum 161
Terminalia ivorensis 180
Terminalia superba 179
Tieghemelia heckelii 181

The five species recommended for amenity plantings include *Liquidambar formosana* (colorful foliage during the summer months), the two *Araucaria* species (symmetrical shape), *Hibiscus elatus* (red flowers), *Eucalyptus deglupta* (multicolored bark), and *Tabebuia heterophylla* (showy pink flowers).

SITE 3

The planting site is in the Waiakea Forest Reserve, approximately 8.4 miles (13 km) southwest of Hilo, on the northeast flank of Mauna Loa. Latitude is 19° 37' north and longitude is 155° 10' west. The elevation is 2050 feet (625 m); aspect is east, with a general slope of 5 percent. Annual rainfall during the last 10 years averaged about 220 inches (5600 mm). September is usually the driest month, averaging about 11 inches (280 mm), and April is usually the wettest month, averaging about 32 inches (800 mm).¹

The soil is Kiloa extremely stony muck. It is usually well drained; permeability is rapid, and runoff is very slow. The layer consists of organic material from 1 to 8 inches (2 to 30 cm) thick, underlain by fragmented aa lava. Kiloa muck has high shrinkage (over 50 percent) upon drying. Roots can penetrate through cracks in the lava to depths of 2 feet (0.7 m) or more (USDA 1973). The soil is strongly acid (pH 5.1) and fertility is low.

Objective—Trials were made to identify tree species useful for timber production.

Results and Recommendations—Three of the 14 species tested appeared promising after 5 years (table 3). *Acacia melanoxylon* was the most outstanding in terms of height growth—4 feet (1.3 m) per year. The Taiwan provenance of *Liquidambar formosana* averaged 3.6 feet (1.1 m) height growth per year, while the Hong Kong source averaged only 1.3 feet (0.4 m). Stem form was also poor for this species on this site. *Araucaria angustifolia*, although growing at an average annual rate of only 2 feet (0.6 m), appears adapted to this site. These three species are recommended for pilot scale planting trials. *Cedrela tonduzii*, rated very promising at age 3 years, has proven unsatisfactory because of terminal dieback and low vigor.

SITE 4

The planting site is in the Waiakea Forest Reserve, about 13 miles (21 km) southwest of Hilo. Latitude is 19° 35' north and longitude is 155° 12' west. The elevation is 2860 feet (870 m); aspect is east, with a general slope of 5 percent. The mean annual rainfall over the last 10 years was about 210 inches (5330 mm). September is usually the driest month, averaging about 10 inches (250 mm) and April is usually the wettest month, averaging about 30 inches (760 mm).¹

Table 3—Performance of species and provenance planted at Site 3, Waiakea Forest Reserve, Hawaii Island, evaluated after 5.3 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		<i>Percent</i>	<i>Feet</i>		<i>Percent</i>	
PROMISING						
<i>Acacia melanoxylon</i> (Uruguay) 365	30	93	22	8 to 32	4.2	78
<i>Araucaria angustifolia</i> (Brazil) 370	5	100	10	3 to 23	1.9	80
<i>Liquidambar formosana</i> (Taiwan) 279	30	100	19	12 to 28	3.6	86
UNSATISFACTORY						
<i>Cardwellia sublimis</i> (Australia) 401	30	70	12	3 to 29	2.3	52
<i>Castanospermum australe</i> (Australia) 285	15	73	4	1 to 9	0.8	0
<i>Cedrela odorata</i> (Trinidad, W.I.) 208	15	53	5	1 to 12	0.9	12
<i>Cedrela tonduzii</i> (Costa Rica) 408	30	100	10	1 to 19	1.9	60
<i>Chukrasia tabularis</i> (India) 331	30	77	4	1 to 19	0.8	4
<i>Cordia alliodora</i> (Costa Rica) 348	30	47	5	1 to 28	0.9	14
<i>Dalbergia sissoo</i> (India) 407	15	87	3	1 to 12	0.6	0
<i>Liquidambar formosana</i> (Hong Kong) 325	30	300	7	1 to 21	1.3	46
<i>Phoebe porosa</i> (Brazil) 412	30	83	3	1 to 10	0.6	8
<i>Tabebuia heterophylla</i> (Puerto Rico) 271	30	97	10	2 to 16	1.9	34

FAILURES: *Melia dubia* 286; *Pterocarpus santalinus* 332.

The soil is Kiloa extremely stony muck. It is usually well drained; permeability is rapid, and runoff is very slow. The surface layer consists of organic material from 1 to 8 inches (2 to 30 cm) thick, underlain by fragmented aa lava. Kiloa muck has high shrinkage (over 50 percent) upon drying. Roots can penetrate through cracks in the lava to depths of 2 feet (0.7 m) or more (USDA 1973). The soil is strongly acid (pH 5.0), and fertility is low.

Objective—Trials were made to identify tree species useful for timber production.

Results and Recommendations—Fourteen species were tested (table 4); *Flindersia brayleyana* was represented by two provenances. After 5.5 years only the Hawaii provenances of *Flindersia brayleyana* and *Eucalyptus robusta* were rated as promising. Both species have proven to be adapted to this rocky, rain-forest area and have been included in general reforestation projects.

Although *Eucalyptus saligna* and *Hibiscus elatus* were not rated promising, they have grown well in reforestation plantings on similar sites. Large variations in soil depth and drainage over short distances resulted in great differences in growth and vigor among individuals of a species. For example, tree heights of *Hibiscus elatus* ranged from 1 to 31 feet (0.3 to 9.4 m) after 5.5 years. Mean annual growth of the 28 surviving trees was 1.8 feet (0.6 m), which we rated unsatisfactory. However, the 17 trees with good

vigor averaged 14 feet (4.3 m) tall, an annual height increment of 2.5 feet (0.8 m).

Maui Island

SITE 5

The planting site is in the Koolau Forest Reserve, on the windward coast of East Maui, about 1 mile (1.6 km) south of the village of Keanae. Latitude is 20° 51' north and longitude is 156° 09' west. The elevation is 420 feet (128 m); aspect is north, with a slope of from 5 percent or less. Mean annual rainfall is about 175 inches (4450 mm), usually well distributed throughout the year. The monthly totals may vary greatly from year to year, however.

The soil is Kailua silty clay, developed from volcanic ash. It is moderately well drained to well drained, permeability is moderately rapid, and runoff is slow. This soil is hard and friable when dry, and sticky and plastic when wet. The soil is very strongly acid (pH 4.7 to 4.9) in both the surface layer and subsoil. It is very low in available phosphorus, potassium, and calcium. These nutrient deficiencies adversely influence growth of most tree species.

Objective—Trials were made to identify tree species useful for timber production.

Results and Recommendations—None of the 13 species planted on this site proved promising after the

Table 4—Performance of species and provenances planted at Site 4, Waiakea Forest Reserve, Hawaii Island, evaluated after 5.5 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
PROMISING			Percent	Feet		Percent
<i>Eucalyptus robusta</i> (Hawaii) 290	30	97	16	1 to 35	2.9	52
<i>Flindersia brayleyana</i> (Hawaii) 219	30	100	11	1 to 28	2.1	63
UNSATISFACTORY						
<i>Eucalyptus saligna</i> (Hawaii) 240	30	53	7	1 to 34	1.3	19
<i>Flindersia brayleyana</i> (Australia) 200	30	100	6	1 to 23	1.1	46
<i>Hibiscus elatus</i> (Puerto Rico) 104	30	93	10	1 to 31	1.8	60
<i>Terminalia ivorensis</i> (Ghana) 180	10	50	10	4 to 21	1.8	60
FAILURES						
<i>Chlorophora excelsa</i> 67		<i>Mansonia altissima</i> 254		<i>Pterocarpus indicus</i> 4		
<i>Entandrophragma utile</i> 186		<i>Pericopsis elata</i> 255		<i>Sindora supa</i> 43		
<i>Gmelina arborea</i> 215		<i>Pterocarpus echinatus</i> 5		<i>Terminalia superba</i> 179		

6.6-year trial period (table 5). Seedling establishment proved difficult on this soil, and growth of most species was poor and erratic. For example, the average height of the seven vigorous *Pterocarpus echinatus* saplings was 23 feet (7 m). The 16 other surviving trees of this species averaged only 7 feet tall. Only one *Pinus kesiya* tree survived. It was straight, vigorous, and 28 feet (8.5 m) tall at age 6.6 years.

Further research should include a pilot-scale planting of *Pterocarpus echinatus* on a related well-drained soil in the area. Soil nutrient deficiencies, especially of phosphorus, should be corrected at the time of planting. Future introduction trials on this soil should emphasize eucalyptus and coniferous species, which have proven to be adapted on related soils.

SITE 6

The planting site is in the Makawao Forest Reserve, located about 3.4 miles (5.5 km) southwest of

the town of Makawao. Latitude is 20° 50' north and longitude is 156° 16' west. Elevation is 3200 feet (975 m); aspect is northwest, with a slope of 10 percent. Average annual rainfall is about 90 inches (2285 mm), well distributed throughout the year. It is usually wettest around March and driest around September, but almost any month can be either the wettest or the driest.

The soil is Olinda silty clay loam, developed in volcanic ash. This soil is well drained; permeability is moderately rapid, and runoff is slow to medium. Soil depth to slightly weathered basic igneous rock ranges from 36 to more than 60 inches (90 to over 150 cm). The soil is friable when dry, and sticky and plastic when wet. It is strongly acid (pH 5.1 to 5.4).

Strong, desiccating winds and low soil fertility adversely influence seedling survival and growth on this narrow, flat ridge.

Objective—Trials were made to identify fast-growing timber species.

Table 5—Performance of species planted at Site 5, Koolau Forest Reserve, Maui Island, evaluated after 6.6 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	Feet			Percent
PROMISING						
None						
UNSATISFACTORY						
<i>Chukrasia tabularis</i> (India) 331	30	¹ 30	3	1 to 4	0.5	11
<i>Hibiscus elatus</i> (Puerto Rico) 104	30	63	10	1 to 25	1.5	31
<i>Liquidambar formosana</i> (Taiwan) 279	30	97	9	1 to 17	1.8	24
<i>Mansonia altissima</i> (Ghana) 254	30	63	4	1 to 9	0.6	5
<i>Pinus kesiya</i> (Viet Nam) 163	30	3	28		4.2	100
<i>Pterocarpus echinatus</i> (Philippine I.) 5	30	77	11	1 to 29	1.7	30
<i>Tectona grandis</i> (New Britain) 406	30	73	6	1 to 15	0.9	0
FAILURES						
<i>Chlorophora excelsa</i> 67		<i>Entandrophragma utile</i> 186		<i>Juglans boliviana</i> 338		
<i>Cordia alliodora</i> 264		<i>Gyrocarpus americanus</i> 328		<i>Swietenia macrophylla</i> 336		

¹ Age 6.1 years.

Results and Recommendations—Twenty-nine species were tested (table 6). Three of these species—*Eucalyptus saligna*, *Araucaria angustifolia*, and *Tabebuia heterophylla*—were represented by two provenances each. After 4.5 years, nine species, including both provenances of *Eucalyptus saligna*, were rated promising. This trial included eight species of eucalyptus, six of which proved adapted to the site. Three coniferous species were rated promising. *Callitris endlicheri* and *Pinus elliottii* grew equally well. Although survival of *Pinus occidentalis* was less than desirable, the vigor expressed by several individuals indicates that this species is adapted to this site. These nine species are recommended for pilot scale plantings.

SITE 7

The planting site is in the Kula Forest Reserve, about 0.8 mile (1.3 km) northeast of Poli-poli Spring State Park. Latitude is 20° 42' north, and longitude is

156° 19' west. The site is on the leeward slope of Mt. Haleakala, a dormant volcano. The elevation is 6360 feet (1940 m); aspect is west, with slopes of from 5 to 38 percent. Mean annual rainfall is about 40 inches (1000 m), but the yearly total varies greatly from year to year. The rainy season is from October to March, when storms usually bring heavy rains. The rest of the year may be very dry. The mean annual temperature is 53° F (12° C). Frosts occur occasionally during the winter. Cloud cover or fog is almost a daily occurrence and influences plant growth. Strong winds commonly cause windthrow where the soil is shallow.

The soil is Laumaia loam, shallow phase, developed from volcanic ash and cinders. It is well drained, permeability is moderately rapid, and runoff is slow. Soil depth is 14 inches (36 cm) to cinders and sand. Some cementation is present and hinders root penetration. This soil is very low in phosphorus, but moderately high in calcium. It is medium acid to slightly acid (pH 5.9 to 6.5).

Table 6—Performance of species and provenances planted at Site 6, Makawao Forest Reserve, Maui Island, evaluated after 4.5 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
PROMISING		Percent	Feet			Percent
<i>Callitris endlicheri</i> (Australia) 330	15	100	12	8 to 17	2.7	100
<i>Eucalyptus botryoides</i> (Uruguay) 366	30	63	19	5 to 31	4.2	94
<i>Eucalyptus microcorys</i> (Brazil) 318	15	53	16	5 to 26	3.6	100
<i>Eucalyptus punctata</i> (Uruguay) 368	30	93	15	4 to 30	3.3	89
<i>Eucalyptus saligna</i> (Hawaii) 345	30	33	25	11 to 35	5.6	90
(Uruguay) 369	30	97	24	6 to 37	5.3	100
<i>Eucalyptus sideroxylon</i> (Uruguay) 372	15	93	19	3 to 26	4.2	92
<i>Eucalyptus tereticornis</i> (Uruguay) 373	30	87	14	3 to 26	3.1	76
<i>Pinus occidentalis</i> (Dominican Rep.) 326	30	50	11	3 to 20	2.4	100
UNSATISFACTORY						
<i>Dalbergia sissoo</i> (India) 403	15	100	5	3 to 7	1.1	80
<i>Eucalyptus camaldulensis</i> (Australia) 444	30	83	11	4 to 24	2.4	76
<i>Eucalyptus deglupta</i> (New Guinea) 350	30	83	6	2 to 13	1.3	24
<i>Liquidambar formosana</i> (Taiwan) 279	29	100	5	3 to 8	1.1	100
<i>Pinus brutia</i> (Turkey) 436	12	100	7	5 to 12	1.6	100

FAILURES:

Apeiba membranacea 382
Araucaria angustifolia 349, 431
Cardwellia sublimis 401
Castanospermum australe 285
Cedrela tonduzii 408

Chukrasia tabularis 331
Manikara hexandra 289
Melia dubia 286
Phoebe porosa 412
Pterocarpus echinatus 5

Pterocarpus santalinus 332
Swietenia macrophylla X *mahagoni* 445
Tabebuia heterophylla 211, 271
Tectona grandis 386
Terminalia ivorensis 180

Strong winds, long dry periods, and shallow soil are the major factors adversely influencing tree growth.

Objective—Trials were made to identify species suitable for the development of multiple use forests; timber products, recreation, and watershed management.

Results and Recommendations—Nine species were tested, and four were rated as promising after 5.6 years (table 7). Three species made satisfactory growth and showed good vigor on this poor site—*Pinus durangensis*, *P. elliottii*, and two provenances of *P. kesiya*. Stem quality of these species was poor.

Some individuals were overtopped by faster growing trees, others were damaged by strong winds. *Pinus engelmannii* proved to be a hardy species, and although growth was slow—1 foot (0.3 m) per year—the trees show good stem form. Planted on the deeper, modal Laumaia soil, these four species could prove useful. They are recommended for inclusion in pilot-scale planting trials.

At age 3 years, all of the *Pinus caribaea* were rated as vigorous and height growth was satisfactory. At age 5.6 years, however, two-thirds of the survivors were sickly.

Table 7—Performance of species and provenances planted at Site 7, Kula Forest Reserve, Maui Island, evaluated after 5.6 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		<i>Percent</i>	<i>Feet</i>			<i>Percent</i>
PROMISING						
<i>Pinus durangensis</i> (Mexico) 23	30	57	14	3 to 24	2.5	82
<i>Pinus elliottii</i> (Georgia) 52	30	83	14	5 to 19	2.5	68
<i>Pinus engelmannii</i> (Mexico) 25	30	77	6	2 to 11	1.1	91
<i>Pinus kesiya</i> (Viet Nam) 163	30	60	13	6 to 19	2.3	83
(Thailand) 188	30	63	11	5 to 17	2.0	84
UNSATISFACTORY						
<i>Pinus caribaea</i> (Bahama I.) 184	30	60	13	9 to 17	2.3	33
<i>Pinus oocarpa</i> (Mexico) 32	30	37	4	1 to 8	0.7	36

FAILURES: *Eucalyptus saligna* 414; *Tetraclinis articulata* 168; *Tristania conferta* 346.

Molokai Island

SITE 8

The planting site is in the Molokai Forest Reserve, 5.7 miles (9.1 km) northeast of the coastal town of Kaunakakai. Latitude is 21° 9' north and longitude is 156° 58', west. The elevation is 2350 feet (716 m); aspect is southwest, with slopes of from 5 to 20 percent. Average annual rainfall is about 40 inches (1000 mm), mostly occurring during the period from October through February.

The soil is Olelo silty clay, formed in material de-

rived from basic igneous rock. It is well drained, permeability is moderately rapid, and runoff is slow. Olelo soil is hard and friable when dry, and very sticky and plastic when wet. It is very strongly acid (pH 4.5 to 5.0).

Strong winds, dry periods, low soil fertility, and competing shrubs are factors limiting tree growth on this site.

Objective—Trials were made to identify tree species useful for erosion control, timber production, and recreational forests.

Results and Recommendations—By the end of the third year none of the 13 species planted proved

adapted to the site (table 8). Adjacent plantings of *Pinus taeda*, *P. elliottii*, and *Eucalyptus saligna* planted by the Hawaii Division of Forestry have grown well. Additional adaptability trials have been established in this area.

Table 8—Species planted at Site 8 Molokai Forest Reserve, Molokai Island, evaluated after 3 years

FAILURES	
<i>Cedrela odorata</i> 208	<i>Pinus occidentalis</i> 326
<i>Cedrela tonduzii</i> 408	<i>Tabebuia heterophylla</i> 271
<i>Chlorophora excelsa</i> 217	<i>Taxodium distichum</i> 182
<i>Chukrasia tabularis</i> 331	<i>Tectona grandis</i> 406
<i>Dalbergia sissoo</i> 407	<i>Tetralinis articulata</i> 168
<i>Liquidambar formosana</i> 279	<i>Tristania conferta</i> 346
<i>Melia dubia</i> 286	

SITE 9

The planting site is in the Molokai Forest Reserve, 6.7 miles (10.8 km) northeast of the coastal town of Kaunakakai. Latitude is 21° 8' north and longitude is 156° 56' west. The elevation is 3250 feet (990 m); aspect is northwest, with slopes of from 4 to 8 percent. Annual rainfall varies greatly from year to year, averaging about 60 inches (1525 mm). There is generally a dry period between June and October.

The soil is Kahanui gravelly silty clay, developed in material weathered from basic igneous rock. It has a discontinuous ironstone sheet at a depth of 12 to 24

inches (30 to 60 cm), which is impermeable to roots. This soil is moderately well drained; permeability is moderately rapid above the ironstone sheet, and run-off is slow to medium. The soil is very strongly acid throughout the profile (pH 4.5 to 5.0), and is deficient in all essential soil nutrients. Trees on this soil develop flat root systems and are subject to windthrow.

Objective—Trials were made to identify tree species useful for timber production.

Results and Recommendations—Thirteen species were tested; four of these proved promising on this poor site after 5.8 years (table 9). Some of the taller trees were windthrown. *Eucalyptus robusta* was included in this planting trial because it was not anticipated that more useful species would grow well, and *E. robusta* is known locally for its ability to grow on wet, poorly drained soils. The annual height growth of both this species and *E. botryoides* was about 6 feet (1.8 m). The most outstanding individual was an *E. botryoides* tree that grew 59 feet (18 m) tall in 6 years.

Acacia melanoxylon and *Liquidambar formosana* grew 3.6 and 2.1 feet (1.1 and 0.6 m) in height, annually. These two species, together with the two eucalypts, are recommended for pilot-scale plantings. All should exhibit better form and resist windthrow when grown under closed stand conditions. Site preparation should include deep plowing to break through the ironstone sheet that hinders normal root development.

Table 9—Performance of species planted at Site 9, Molokai Forest Reserve, Molokai Island, evaluated after 5.8 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		<i>Percent</i>	<i>Feet</i>			<i>Percent</i>
PROMISING						
<i>Acacia melanoxylon</i> (California) 1	10	70	21	11 to 31	3.6	71
<i>Eucalyptus botryoides</i> (Uruguay) 366	30	67	35	10 to 59	6.0	80
<i>Eucalyptus robusta</i> (Brazil) 322	15	73	34	23 to 45	5.9	81
<i>Liquidambar formosana</i> (Taiwan) 279	30	97	12	5 to 16	2.1	96
UNSATISFACTORY						
<i>Chamaecyparis thyoides</i> (Virginia) 172	15	20	9	7 to 10	1.6	33
<i>Tristania conferta</i> (Hawaii) 346	30	40	10	1 to 17	1.7	66

FAILURES:

<i>Chlorophora excelsa</i> 354	<i>Melia dubia</i> 286	<i>Tectona grandis</i> 406
<i>Chukrasia tabularis</i> 331	<i>Pinus occidentalis</i> 326	<i>Terminalia ivorensis</i> 180
<i>Cordia alliodora</i> 264		

Oahu Island

SITE 10

This planting site is on the Lualualei Naval Magazine, on the dry leeward coast 4 miles (6 km) east of Waianae. Latitude is 21° 27' north and longitude is 158° 07' west. The elevation is 250 feet (76 m); aspect is west, and the topography is nearly level. The annual rainfall is about 20 inches (500 mm), mostly occurring between November and April. There are often prolonged dry periods during the summer months.

The soil is Lualualei clay, developed in alluvium and colluvium. It is well drained, and permeability and runoff are slow. When wet, this montmorillonitic soil is very sticky and very plastic. During dry periods it becomes very hard and cracks develop, often to depths of 3 feet (1 m) and widths of from 1 to 4 inches (2 to 10 cm) (McCall 1973). Plant roots may be broken by soil shrinkage. Some roots, however, penetrate to a depth of 5 feet (1.5 m) or more. Lualualei clay is medium acid to neutral (pH 6.0 to 6.6).

Strong winds, long dry periods, the shrink-swell properties of the soil, and vigorous plant competition strongly influence survival and growth of planted trees on this site.

Objective—Trials were made to identify tree species useful for the development of protection forests, for amenity plantings, and to provide shade and shelter for livestock.

Results and Recommendations—Twenty-four species were tested, but only two were rated as promising after 5 years (table 10). Only *Eucalyptus camaldulensis* and *Phytolacca dioica* surpassed a desirable annual growth rate of 2 feet (0.6 m) on this dry site. *Eucalyptus camaldulensis* proved outstanding, averaging nearly 4 feet (1.2 m) of height growth per year. *Phytolacca dioica* had high initial mortality (87 percent) but the two surviving trees were vigorous and grew at an annual rate of 2.4 feet in height. This species is also suitable for providing shelter and shade for livestock.

These two promising species are recommended for pilot scale planting trials, where their growth and development under closed stand conditions can be determined. Future introduction trials on this site should again include five species that had fairly good survival and vigor, although growth was slow: *Callitris endlicheri*, *Cordia subcordata*, *Gyrocarpus americanus*, *Melia azedarach*, and *Tetralinis articulata*. Two eucalypts, *Eucalyptus punctata* and *E. tereticornis*, suffered high initial mortality, and should also be tested again.

Table 10—Performance of species and provenances planted at Site 10, Lualualei, Oahu Island, evaluated after 5.0 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
PROMISING			Percent	—————Feet—————		Percent
<i>Eucalyptus camaldulensis</i> (Uruguay) 245	30	57	19	7 to 30	3.9	94
<i>Phytolacca dioica</i> (Argentina) 259	15	13	12	9 to 15	2.4	100
UNSATISFACTORY						
<i>Berrya cordifolia</i> (Ceylon) 314	30	17	3	2 to 4	0.6	100
<i>Callitris endlicheri</i> (Australia) 330	28	11	6	5 to 8	1.2	100
<i>Cordia subcordata</i> (Hawaii) 449	15	47	6	4 to 9	1.2	71
<i>Gyrocarpus americanus</i> (Kenya) 328	30	63	5	3 to 8	1.1	89
<i>Melia azedarach</i> (Cyprus) 261	15	60	6	4 to 9	1.2	88
<i>Tectona grandis</i> (Australia) 406	30	33	7	1 to 11	1.4	80
<i>Tetralinis articulata</i> (Tunisia) 168	30	7	5	4 to 5	1.0	100
<i>Thespesia populnea</i> (Hawaii) 448	15	13	6	3 to 8	1.2	50

FAILURES:

Chlorophora excelsa 354
Cordia alliodora 177, 264
Cupressus sempervirens 169
Dalbergia sissoo 407
Eucalyptus camaldulensis 367

Eucalyptus macrorrhyncha 443
Eucalyptus punctata 368
Eucalyptus tereticornis 373
Liquidambar formosana 325
Pinus brutia 438

Roseodendron donnell-smithii 272
Swietenia macrophylla 336
Tabebuia heterophylla 271
Tristania conferta 346

SITE 11

This planting site is at the Lualualei Naval Magazine, 5 miles (8 km) east of Waianae. Latitude is 21° 27' north, and longitude is 158° 07' west. The elevation is 580 feet (177 m); aspect is west, with a slope of 12 percent. The mean annual rainfall is about 28 inches (700 mm), mostly occurring between November and April. There are prolonged dry periods during the summer months.

The soil is Lualualei clay, stoney phase, developed in alluvium and colluvium (USDA 1972). This soil is well drained; permeability and runoff are slow. This montmorillonitic soil is very sticky and very plastic when wet. During dry periods the soil becomes very hard, and cracks develop, often to depths of 3 feet (1 m) and from 1 to 4 inches (2 to 10 cm) in width (McCall 1973). Plant roots may be broken by this soil shrinkage. Some roots, however, penetrate to depths of 5 feet (1.5 m) or more. Lualualei clay, stony phase, is medium acid to neutral (pH 5.8 to 7.0). It differs from the soil at Site 10 in that there are many stones and boulders on the surface and throughout the profile.

Strong winds, extended dry periods, the shrink-swell properties of the soil, and vigorous plant competition strongly influence survival and growth. Also, on occasion, small trees are damaged by giant African snails (*Acnatina fulica* Bowditch).

Objective—Trials were made to identify tree species useful for the development of protection forests, and to evaluate their potential for timber, amenity plantings, and Christmas trees.

Results and Recommendations—Nineteen species were tested, 11 of which were judged promising after 5.6 years (table 11). *Eucalyptus camaldulensis* and *Phytolacca dioica* were the most promising species in height growth, averaging 27 feet (8 m) and 23 feet (7 m) respectively. *Eucalyptus camaldulensis* appears useful for protection forest development and for timber, fuelwood, and wood fiber production. *Phytolacca dioica* appears ideal for livestock shelter and shade, and for amenity plantings.

Cordia alliodora, *Swietenia macrophylla*, *Tectona grandis*, and *Tetraclinis articulata* are among the species that performed satisfactorily. *Tectona grandis* is included in this group despite its relatively slow growth (for this species); its success is contingent

Table 11—Performance of species planted at Site 11, Lualualei, Oahu Island, evaluated after 5.6 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
PROMISING		Percent	Feet			Percent
<i>Araucaria columnaris</i> (Hawaii) 453	30	30	5	1 to 9	0.9	77
<i>Callitris endlicheri</i> (Australia) 330	30	20	12	4 to 16	2.1	83
<i>Cordia alliodora</i> (Costa Rica) 264	30	77	11	5 to 21	2.0	82
<i>Cordia subcordata</i> (Hawaii) 449	15	100	7	2 to 12	1.2	66
<i>Eucalyptus camaldulensis</i> (Uruguay) 367	15	73	26	15 to 38	4.6	90
<i>Phytolacca dioica</i> (Argentina) 259	15	87	23	18 to 29	4.1	100
<i>Roseodendron donnell-smithii</i> (Puerto Rico) 272	5	60	8	2 to 11	1.4	100
<i>Swietenia macrophylla</i> (British Honduras) 336	5	60	15	13 to 19	2.7	100
<i>Tectona grandis</i> (Australia) 406	30	100	11	3 to 19	2.0	93
<i>Tetraclinis articulata</i> (Tunisia) 168	24	71	8	4 to 13	1.4	82
<i>Thespesia populnea</i> (Hawaii) 448	15	93	11	6 to 14	2.0	100
UNSATISFACTORY						
<i>Berrya cordifolia</i> (Ceylon) 314	15	60	8	5 to 14	1.4	66
<i>Cedrela odorata</i> (Trinidad W.I.) 208	15	73	13	8 to 18	2.3	90
<i>Chlorophora excelsa</i> (Uganda) 354	30	83	9	3 to 16	1.6	84
<i>Dalbergia sissoo</i> (India) 407	15	67	11	4 to 22	2.0	60
<i>Tabebuia heterophylla</i> (Puerto Rico) 271	15	20	6	4 to 8	1.1	33
<i>Cratania conferta</i> (Hawaii) 346	30	50	18	8 to 23	3.2	100

FAILURES: *Liquidambar formosana* 325; *Pinus brutia* 438.

upon continuous weeding until it overtops the brush.

Thespesia populnea and *Cordia subcordata*, small trees valued for craftwood, grew well enough to merit further plantings; *Callitris endlicheri*, which also produces valuable wood (Streets 1962), had high initial mortality but survivors have satisfactory growth, vigor, and stem form. Two of the three surviving *Roseodendron donnel-smithii* trees were vigorous and averaged 11 feet (3.4 m) tall. This species—gold tree—is one of the most beautiful of the large ornamental trees planted in the tropics. *Araucaria columnaris*, valued as a handsome ornamental and for Christmas trees, is promising even though it grew slowly. Its color and general attractiveness could be improved with fertilizer applications.

Tristania conferta and *Dalbergia sissoo* looked very promising initially, but are now rated as unsatisfactory. Mortality in *Tristania conferta* was caused by severe droughts and subsequent attacks by wood borers. The growth rate of *Dalbergia sissoo* has decreased greatly during the last 2.5 years. *Cedrela odorata* and *Chlorophora excelsa* now suffer from terminal dieback, and their value on this site is questioned. *Berrya cordifolia* suffered repeated attacks by the Chinese rose beetle (*Adoretus sinicus* Burmeister).

The 11 species rated as promising after a 5.6-year trial period are recommended for pilot scale plantings on this site.

SITE 12

The planting site is on the Lualualei Naval Magazine, about 5 miles (8 km) east of Waiānae. Latitude is 21° 27' north and longitude is 158° 07' west. The

elevation is 580 feet (177 m); aspect is west with a slope of 12 percent. The mean annual rainfall is about 28 inches (700 mm), mostly occurring between November and April. There are long dry periods during the summer months.

The soil is Ewa silty clay, developed in alluvium derived from basic igneous rock. It is well drained, permeability is moderate, and runoff is slow. This soil is sticky and plastic when wet, but becomes very hard upon drying. Ewa silty clay is medium acid to slightly acid (pH 5.8 to 6.5).

Strong winds during the winter months, extended dry periods, and vigorous plant competition are the major limiting factors for tree growth on this site.

Objective—Trials were made to identify tree species useful for the development of protection forests and to evaluate their potential for timber and amenity plantings.

Results and Recommendations—Six of the 12 species tested were rated as promising after 6.6 years (table 12). *Acacia implexa*, the most promising species averaged 23 feet (7 m) in height. *Acacia melanoxylon*, a tree closely related to *A. implexa* (Streets 1962), failed on this low-elevation dry site. Two conifers, *Callitris endlicheri* and *Tetraclinis articulata*, appear well adapted, growing about 2 feet (0.6 m) in height annually. *Melia azedarach* had high survival and good vigor, but averaged only 1.4 feet (0.5 m) in height growth per year. *Tectona grandis* grew well enough to be utilized in protection forest plantings. *Cordia alliodora*, *Pithecellobium saman*, and *Pterocarpus echinatus* suffered from terminal dieback, and at present do not appear promising.

Table 12—Performance of species planted at Site 12, Lualualei, Oahu Island, evaluated after 6.6 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		<i>Percent</i>	<i>Feet</i>			<i>Percent</i>
PROMISING						
<i>Acacia implexa</i> (Australia) 69	9	78	23	20 to 26	3.5	100
<i>Callitris endlicheri</i> (Australia) 330	18	56	12	5 to 19	1.8	100
<i>Chlorophora excelsa</i> (Uganda) 217	18	72	11	6 to 16	1.7	92
<i>Melia azedarach</i> (Cyprus) 261	18	89	9	5 to 14	1.4	81
<i>Tectona grandis</i> (Australia) 406	18	78	12	2 to 22	1.8	64
<i>Tetraclinis articulata</i> (Tunisia) 168	18	100	13	2 to 16	2.0	94
UNSATISFACTORY						
<i>Cordia alliodora</i> (Costa Rica) 348	18	33	11	4 to 11	1.7	66
<i>Pithecellobium saman</i> (Hawaii) 411	15	80	11	1 to 15	1.7	67
<i>Pterocarpus echinatus</i> (Philippine I.) 5	18	94	10	4 to 16	1.5	76

FAILURES: *Acacia melanoxylon* 98; *Hibiscus elatus* 104; *Tristania conferta* 410.

All six of the species rated as promising are recommended for pilot-scale plantings on this site.

Kauai Island

SITE 13

Two planting sites were on Hawaii Homes Authority lands, about 1 mile (1.6 km) south of the town of Hanalei. Latitude is 22° 11' north, and longitude is 159° 30' west. The trials are on upland flats and terraces at elevations between 100 and 200 feet (30 and 60 m). Aspect varies from north to east, with slopes of from 1 to 14 percent. The mean annual rainfall is 100 inches (2540 mm) distributed uniformly throughout the year.

The soil is Hanamaulu silty clay, developed in alluvium washed from upland areas. It is found on stream terraces, and is moderately well drained, permeability is moderately rapid, and runoff is slow. Hanamaulu silty clay is very strongly acid (pH 4.5 to 5.0), with

very low soil fertility. Soil nutrient deficiencies are related to the high soil acidity and aluminum toxicity, characteristics of this soil.

Objective—Trials were made to identify tree species suitable for timber production and erosion control.

Results and Recommendations—None of the 31 species planted met our criteria of a promising species (table 13). A few individuals of three species—*Acacia melanoxylon*, *Eucalyptus grandis*, and *Flindersia brayleyana*—exceeded 20 feet (6 m) at age 5.0 years. On the average, growth of all species was disappointing, vigor was poor, and mortality was high. Follow-up pilot scale plantings of *Acacia melanoxylon* and *Flindersia brayleyana* on the same area failed. Correction of the soil nutrient deficiencies appears to be necessary on this site to obtain satisfactory survival and initial growth. Studies on the effects of soil amendments and fertilizers on the growth of selected species, primarily other eucalypts, are recommended for this site.

Table 13—Performance of species planted at Site 13, near Hanalei, Kauai Island, evaluated after 5 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
		Percent	Feet			Percent
PROMISING						
None						
UNSATISFACTORY						
<i>Acacia melanoxylon</i> (Hawaii) 379	5	40	23	19 to 26	4.6	100
<i>Araucaria columnaris</i> (Hawaii) 239	25	96	2	1 to 4	0.4	45
<i>Cassia siamea</i> (Hawaii) 303	30	17	3	1 to 5	0.6	40
<i>Eucalyptus citriodora</i> (Hawaii) 359	30	23	2	1 to 5	0.4	14
<i>Eucalyptus deglupta</i> (Hawaii) 378	30	23	6	1 to 16	1.2	42
<i>Eucalyptus grandis</i> (Hawaii) 357	30	77	6	2 to 26	1.2	21
<i>Flindersia brayleyana</i> (Australia) 275	25	60	5	1 to 20	1.0	46
<i>Fraxinus uhdei</i> (Hawaii) 361	30	67	3	0 to 10	0.6	35
<i>Gmelina arborea</i> (Ceylon) 196	25	60	3	1 to 6	0.6	46
<i>Hibiscus elatus</i> (Puerto Rico) 104	30	70	2	1 to 6	0.4	0
<i>Khaya nyasica</i> (Hawaii) 358	5	60	3	2 to 4	0.6	33
<i>Liquidambar formosana</i> (Taiwan) 324	10	80	2	1 to 4	0.4	37
<i>Pterocarpus echinatus</i> (Philippine I.) 5	30	80	3	1 to 9	0.6	4
<i>Sindora supa</i> (Philippine I.) 43	5	40	1	1 to 1	0.2	50
<i>Swietenia macrophylla</i> (Hawaii) 238	9	22	3	1 to 4	0.6	50
<i>Terminalia ivorensis</i> (Nigeria) 204	30	53	2	1 to 4	0.4	31

FAILURES:

Agathis australis 213
Amburana sp. 89
Castanospermum australe 185
Cedrela odorata 208
Chlorophora excelsa 67

Cordia alliodora 177
Dacrydium cupressinum 270
Eucalyptus pilularis 360
Mansonia altissima 254
Pericopsis elata 255

Pithecellobium saman 237
Roseodendron donnell-smithii 301
Serialbizzia acle 102
Terminalia superba 80
Toona ciliata v. *australis* 362

SITE 14

The planting site is on the Lihue-Koloa Forest Reserve, 8 miles (13 km) west of the coastal town of Kapaa. Latitude is 22° 03' north, and longitude is 159° 27' west. The elevation is 720 feet (220 mm); aspect is northeast, with slopes of from 0 to 5 percent. Annual rainfall averages about 100 inches (2540 mm), but varies greatly from year to year.

The soil is Hanamaulu silty clay, developed in alluvium washed from upland areas. It is found on stream terraces, and is moderately well drained, permeability is moderately rapid, and runoff is slow. Hanamaulu silty clay is very strongly acid (pH 4.5 to 5.0) and very infertile. It is not as well drained and not as deep as the Hanamaulu soil on Site 13.

Objective—Trials were made to identify tree species suitable for timber production.

Results and Recommendations—Twelve species were tested, but only three showed promise for timber production after 5 years (table 14). *Eucalyptus camaldulensis* had a mean annual growth of 10 feet (3 m). *E. deglupta* averaged 5 feet (1.5 m) of height growth annually even though several trees were overtopped by their neighbors. *Liquidambar formosana* exhibited satisfactory growth and high vigor but the provenance tested had poor stem form—that is, multiple stems and forks—limiting its value as a timber tree.

Acacia melanoxylon made satisfactory height growth, but at age 5 years, the trees appeared sickly and were dying. *Cardwellia sublimis* grew well—nearly

4 feet (1.2 m) per year—but had very poor form. *Tectona grandis* had high survival, but stem form was poor.

Eucalyptus camaldulensis and *E. deglupta* should be further tested in pilot scale plantings on this site. *Liquidambar formosana* should also be included, if seed from superior mother trees on Taiwan can be obtained.

SITE 15

The planting site is on the Lihue-Koloa Forest Reserve, about 7.2 miles (11.6 km) west of Kapaa. Latitude is 22° 04' north and longitude is 159° 26' west. The elevation is 780 feet (238 m); aspect is east, with slopes of from 2 to 5 percent. Annual rainfall averaged 116 inches (2950 mm) between 1919 and 1966. Extremes recorded during this period ranged from 59 inches (1500 mm) to 151 inches (3835 mm).

The soil is Haliu gravelly silty clay, developed in material weathered from basic igneous rock and mixed with volcanic ash. It is well drained, permeability is moderately rapid, and runoff is slow. The shallow surface horizon contains ironstone gravel and a coarse sand. This soil is extremely acid to very strongly acid (pH below 4.5 to 4.6).

The principal factors which adversely affect seedling survival and subsequent growth on this site are low soil fertility and severe weed competition.

Objective—Trials were made to identify tree species suitable for timber production.

Table 14—Performance of species planted at Site 14, Lihue-Koloa Forest Reserve, Kauai Island, evaluated after 5 years

Species, seed source, and Hawaii seed lot number	Trees planted	Survival	Height			Good vigor
			Average	Range	Annual growth	
PROMISING		Percent	Feet			Percent
<i>Eucalyptus camaldulensis</i> (Uruguay) 367	30	90	51	28 to 73	10.0	92
<i>Eucalyptus deglupta</i> (New Britain) 428	30	77	26	4 to 43	5.1	47
<i>Liquidambar formosana</i> (Taiwan) 279	30	90	19	13 to 28	3.7	100
UNSATISFACTORY						
<i>Acacia melanoxylon</i> (Uruguay) 365	30	47	21	8 to 37	2.7	14
<i>Araucaria angustifolia</i> (Brazil) 431	30	53	3	1 to 30	0.6	43
<i>Cardwellia sublimis</i> (Australia) 401	15	20	20	18 to 21	3.9	100
<i>Cedrela odorata</i> (Trinidad, W.I.) 208	30	33	9	2 to 28	1.8	20
<i>Chukrasia tabularis</i> (India) 331	30	83	5	1 to 14	1.0	16
<i>Tectona grandis</i> (Costa Rica) 418	30	97	12	1 to 22	2.4	65

FAILURES: *Cordia alliodora* 393; *Pithecellobium saman* 527; *Roseodendron donnell-smithii* 301.

Results and Recommendations—Only three of the 18 species tested indicated promise for timber production (table 15). *Eucalyptus deglupta* averaged about 15 feet (4.6 m) in height, an annual increment of 2.6 feet (0.8 m). Heights of 6-year-old *Hibiscus elatus* varied greatly, ranging from 3 to 34 feet (1 to 10 m). The smaller, less vigorous trees suffered from terminal dieback. Stem form of this species was unsatisfactory but should improve if grown under closed stand conditions. This is also true for *Liquidambar formosana*.

Only *Eucalyptus deglupta* is recommended for a pilot scale planting trial on Hali soil when the soil pH is 4.7 or lower. Where the soil pH is higher than 4.7, *Hibiscus elatus* and *Liquidambar formosana* are also recommended. Seeds of these two species should be collected from mother trees of superior form.

SITE 16

The planting site is in the Puu Ka Pele Forest Re-

serve, on a dry leeward ridge about 16 miles (26 km) northwest of Waimea town. Latitude is 22° 05' north and longitude is 159° 42' west. The elevation is 2350 feet (716 m); aspect is west, with a slope of 5 percent. Mean annual rainfall is about 38 inches (965 mm). Long dry periods occur almost every summer.

The soil is Mahana silt loam, developed in volcanic ash. It is well drained, permeability is moderately rapid, and runoff is slow. This soil is highly weathered and extremely erodible. The silty materials in this soil consist largely of iron or titanium minerals, concentrated near the surface. Mahana silt loam ranges in soil acidity from very strongly acid to strongly acid (pH 4.9 to 5.2).

Limiting factors for seedling establishment and growth include the long dry periods, low soil fertility, and shallow soils.

Objectives—Trials were made to identify tree species suitable for erosion control, watershed protection, and recreation forests. Timber production is a secondary consideration on this forest reserve.

Table 15—Performance of species and provenances planted at Site 15, Lihue-Koloa Forest Reserve, Kauai Island

Species, seed source, and Hawaii seed lot number	Trees planted	Age	Survival	Height			Good vigor
				Average	Range	Annual growth	
PROMISING		<i>Years</i>	<i>Percent</i>	<i>Feet</i>			<i>Percent</i>
<i>Eucalyptus deglupta</i> (Hawaii) 302	30	5.7	97	15	7 to 24	2.6	68
<i>Hibiscus elatus</i> (Puerto Rico) 104	30	5.8	100	17	3 to 34	2.9	83
<i>Liquidambar formosana</i> (Taiwan) 279	30	4.8	97	10	4 to 17	2.1	72
UNSATISFACTORY							
<i>Agathis australis</i> (New Zealand) 269	30	4.8	57	2	1 to 4	0.4	11
<i>Araucaria angustifolia</i> (Brazil) 431	33	4.8	88	3	1 to 9	0.6	82
<i>Cassia siamea</i> (Hawaii) 303	30	5.8	97	10	2 to 28	1.7	58
<i>Chukrasia tabularis</i> (India) 331	30	4.8	50	2	1 to 4	0.4	46
<i>Cordia alliodora</i> (Costa Rica) 177	30	4.8	37	2	1 to 6	0.4	9
<i>Pterocarpus echinatus</i> Philippine I.) 5	30	5.8	97	7	1 to 16	1.2	55

FAILURES:

Castanospermum australe 285
Chlorophora excelsa 67
Entandrophragma utile 186

Flindersia brayleyana 200
Mansonia altissima 254
Melia dubia 286

Pericopsis elata 255
Roseodendron donnell-smithii 301
Swietenia mahagoni 221

Results and Recommendations—Fourteen species were appraised over a 7-year period (table 16). Two eucalypts and four conifers grew well, and were rated as promising. *Eucalyptus camaldulensis* grew nearly 6 feet (1.8 m) annually. This species would be a good substitute for the commonly planted *E. saligna* and *E. grandis* at lower elevations on these ridges, where the rainfall is lower. *Eucalyptus punctata* averaged 5 feet (1.5 m) in height growth annually, but generally its vigor and stem form varied greatly. The shade-tolerant *Callitris endlicheri*, which grew relatively slowly but exhibited good survival and form, appears suitable for underplanting in eucalyptus plantations.

Pinus kesiya (Viet Nam provenance), *P. caribaea* var. *bahamensis* and its close relative *P. occidentalis* all grew nearly 5 feet (1.4 m) per year. For several years, one-third of the *P. caribaea* trees exhibited the stem characteristic called “foxtailing”—that is, no lateral branch development. *Eucalyptus tereticornis* had very poor form.

Eucalyptus camaldulensis and *Pinus caribaea* var. *bahamensis* were outstanding species on this site. Pilot-scale planting trials should include these species as well as *P. kesiya* and *Callitris endlicheri*. *P. occidentalis* should again be tested in species introduction trials, as the few survivors grew rapidly.

Table 16—Performance of species and provenances planted at Site No. 16, Puu Ka Pele Forest Reserve, Kauai Island

Species, seed source, and Hawaii seed lot number	Trees planted	Age	Survival	Height			Good vigor
				Average	Range	Annual growth	
PROMISING		<i>Years</i>	<i>Percent</i>	<i>Feet</i>			<i>Percent</i>
<i>Callitris endlicheri</i> (Australia) 439	30	4.8	97	10	3 to 14	2.1	96
<i>Eucalyptus camaldulensis</i> (Uruguay) 367	30	4.8	97	28	2 to 42	5.8	89
<i>Eucalyptus punctata</i> (Uruguay) 368	30	4.8	90	24	7 to 39	5.0	62
<i>Pinus caribaea</i> v. <i>bahamensis</i> (Bahama I.) 184	30	6.8	83	31	17 to 41	4.6	96
<i>Pinus kesiya</i> (Viet Nam) 163	30	6.0	53	29	21 to 36	4.8	100
<i>Pinus occidentalis</i> (Dominican Rep.) 327	28	6.0	7	29	29 to 29	4.8	100
UNSATISFACTORY							
<i>Eucalyptus tereticornis</i> (Uruguay) 373	30	4.8	83	19	3 to 43	4.0	40
<i>Pinus brutia</i> (Turkey) 436	24	4.8	92	5	3 to 7	1.0	95
<i>Pinus durangensis</i> (Mexico) 111	20	5.8	90	5	2 to 8	0.9	100
<i>Pinus rudis</i> (Mexico) 130	30	5.8	57	3	0 to 7	0.5	82

FAILURES:

<i>Cupressus sempervirens</i> 170	<i>Pinus insularis</i> 40	<i>Pinus occidentalis</i> 326
<i>Pinus canariensis</i> 174	<i>Pinus kesiya</i> 188	<i>Pinus pinaster</i> 339
<i>Pinus hartwegii</i> 114		

CONCLUSIONS — A LOOK INTO THE FUTURE

As summarized in the appendix (table 19), ten conifers and 32 hardwood species may have use for timber production, craftwood, roadside beautification, protection forests, or brush control. At some of the trial sites, several species grew well; at other sites few or none of the species proved well adapted. The performance of most of the high-quality hardwood species tested was disappointing at most sites. Those high-quality wood species rated unsatisfactory because their survival and growth were somewhat erratic should again be included in subsequent adaptability trials. For these species, intensive silvicultural

management practices appear to be both necessary and justified. These practices would emphasize fertilizer treatments and weed control.

We attribute many failures and low vigor to adverse site conditions—for example, low soil fertility, droughts, desiccating winds, and weed competition. Most mortality occurred during the first few months following outplanting. Most species from the humid torrid zones, especially tropical African species, were not at home in Hawaii’s cool rain forests.

The next phase in our experimental program for species selection is the establishment of pilot scale

planting trials. In these trials most of the species judged "promising" for timber in our adaptability trials will be grown under closed stand conditions and will be critically evaluated. Concurrent research is needed, including fertilizer trials to assure rapid initial growth, provenance trials to identify the best seed sources for Hawaii's conditions, and propagation of plus trees selected from older forest plantations.

Very recently there has been a great increased demand in the world market for wood fiber. At the same time, the energy crisis has forced a reappraisal of the place of wood for fuel. In today's market fuelwood may be an economically feasible substitute for oil in the production of electricity in Hawaii. Many species which may be adapted to Hawaii's low-quality sites can be used for fiber and fuel. Hawaii's forest lands are capable of growing such products at exceptionally high rates. Many of the eucalypts and true pines, rated promising in this report or proven so in

earlier plantings, could help meet this increased demand on the world's forests.

Callitris spp. and other conifers have performed well on arid sites in Hawaii. These deserve greater local recognition for reforestation currently unproductive wildlands.

Close cooperation by research agencies in other countries contributed markedly to the progress of the investigations described here. Continuance of this cooperation, by mutual exchange of information and plant material, will permit increased research productivity along the lines described briefly above.

Although these adaptability trials were designed primarily to screen the initial performance of selected species, further observations and reevaluations are recommended at age 10 years. Losses or damage from disease or from destructive insects, or a radical change in growth, would give cause to revise the performance rating of a species.

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APPENDIX

Table 17--Species index for Hawaii adaptability trials,
identifying seed sources, locations where planted by
study site number, and performance rating (P, Promising;
U, Unsatisfactory; F, Failure)

Species	Hawaii seed lot number	Seed source	Study site number and rating
Acacia implexa Benth.	69	Australia	12-P
A. melanoxylon R. Br.	1	California	9-P
	98	Italy	12-F
	365	Uruguay	3-P, 14-U
	379	Hawaii	13-U
Agathis australis (D. Don in Lamb.) Salisb.	213	New Zealand	2-U, 13-F
	269	New Zealand	15-U
Albizia falcataria (L.) Fosberg	203	Hawaii	1-P
Amburana sp.	89	Peru	2-F, 13-F
Apeiba membrancea Spruce	382	Peru	6-F
Araucaria angustifolia (Bert.) Kuntze	300	Argentina	2-P
	349	Argentina	6-F
	364	Brazil	2-P
	370	Brazil	3-P
	431	Brazil	6-F, 14-U, 15-U
A. columnaris (Forst. f.) Hook	239	Hawaii	1-P, 13-U
	398	Hawaii	2-P
	453	Hawaii	11-P
Berrya cordifolia (Willd.) Burret	314	Ceylon	2-F, 10-U, 11-U
Brosimum sp.	383	Peru	2-F
Callitris endlicheri (Parl.) F.M. Bail.	330	Australia	6-P, 10-U, 11-P, 12-P
	439	Australia	16-P
Cardwellia sublimis F.v.M.	401	Australia	2-U, 3-U, 6-F, 14-U
Cassia siamea Lam.	303	Hawaii	13-U, 15-U
Castanospermum australe A. Cunn.	285	Australia	2-U, 3-U, 6-F, 13-F, 15-F
Cedrela odorata L.	143	Mexico	2-U
	144	Mexico	2-P
	208	Trinidad, W. I.	2-U, 3-U, 8-F, 11-U
C. tonduzii C. DC.	408	Costa Rica	3-U, 6-F, 8-F
Chamaecyparis thyoides (L.) B.S.P.	172	Virginia	9-U

Species	Hawaii seed lot number	Seed source	Study site number and rating
<i>Chlorophora excelsa</i> Benth. & Hook. f.	67	Nigeria	1-U, 2-F, 4-F, 5-F, 13-F, 15-F
	217	Uganda	8-F, 12-P
	354	Uganda	9-F, 10-F, 11-U
<i>Chukrasia tabularis</i> A. Juss.	331	India	2-P, 3-U, 5-U, 6-F, 8-F, 9-F, 14-U, 15-U
<i>Cordia alliodora</i> (Ruiz & Pav.) Oken	177	Cost Rica	2-U, 10-F, 13-F, 15-U
	264	Cost Rica	2-U, 5-F, 9-F, 10-F, 11-P
	348	Costa Rica	3-U, 12-U
	393	Venezuela	2-U, 14-F
	395	Fiji	2-U
<i>C. subcordata</i> Lam.	449	Hawaii	10-U, 11-P
<i>Cupressus sempervirens</i> L.	169	Tunisia	10-F
	170	Tunisia	16-F
<i>Dacrydium cupressinum</i> Soland.	270	New Zealand	13-F
<i>Dalbergia sissoo</i> Roxb.	403	India	6-U
	407	India	3-U, 8-F, 10-F, 11-U
<i>Entandrophragma utile</i> Sprague	186	Ghana	1-F, 4-F, 5-F, 15-F
<i>Eucalyptus botryoides</i> Sm.	366	Uruguay	6-P, 9-P
<i>E. camaldulensis</i> Dehnh.	245	Hawaii	10-P
	367	Uruguay	10-F, 11-P, 14-P, 16-P
	444	Australia	6-U
<i>E. citriodora</i> Hook.	246	Hawaii	1-P
	359	Hawaii	13-U
<i>E. deglupta</i> Blume	227	Australia	2-P
	302	Hawaii	15-P
	350	New Guinea	6-U
	378	Hawaii	13-U
	428	New Britain	14-P
<i>E. grandis</i> (Hill) Maiden	357	Hawaii	13-U
<i>E. macrorrhyncha</i> F.v.M.	443	Australia	10-F
<i>E. microcorys</i> F.v.M.	318	Brazil	6-P
<i>E. pilularis</i> Sm.	360	Hawaii	13-F
<i>E. punctata</i> DC.	368	Uruguay	6-P, 10-F, 16-P
<i>E. robusta</i> Sm.	290	Hawaii	4-P
	322	Brazil	9-P
<i>E. saligna</i> Sm.	240	Hawaii	4-U

Species	Hawaii seed lot number	Seed source	Study site number and rating
	345	Hawaii	6-P
	369	Uruguay	6-P
	414	Hawaii	7-F
<i>E. sideroxylon</i> A. Cunn. ex. Benth.	372	Uruguay	6-P
<i>E. tereticornis</i> Sm.	373	Uruguay	6-P, 10-F, 16-U
<i>Flindersia brayleyana</i> F.v.M.	200	Australia	1-P, 2-U, 4-U, 15-F
	219	Hawaii	1-P, 2-P, 4-P
	375	Australia	13-U
<i>Fraxinus uhdei</i> (Wenzig) Lingelsh.	15	California	2-U
	361	Hawaii	13-U
<i>Gmelina arborea</i> L.	196	Ceylon	13-U
	215	India	4-F
<i>Grevillea robusta</i> A. Cunn.	225	Hawaii	2-P
<i>Gyrocarpus americanus</i> Jacq.	328	Kenya	2-F, 5-F, 10-U
<i>Hibiscus elatus</i> Sw.	104	Puerto Rico	1-P, 2-P, 4-U, 5-U, 12-F, 13-U, 15-P
<i>Juglans australis</i> Griseb.	400	Bolivia	2-U
<i>J. boliviana</i> (C. DC.) Dode	338	Cost Rica	2-U, 5-F
<i>Khaya nyasica</i> Stapf ex Baker f.	358	Hawaii	13-U
<i>Liquidambar formosana</i> Hance	279	Taiwan	3-P, 5-U, 6-U, 8-F, 9-P, 14-P, 15-P
	324	Taiwan	2-P, 13-U
	325	Hong Kong	2-P, 3-U, 10-F, 11-F
<i>Maesopsis eminii</i> Engl.	293	Kenya	2-U
<i>Manilkara hexandra</i> (Roxb.) Dubard	289	Ceylon	6-F
<i>Mansonia altissima</i> A. Chev.	254	Ghana	1-F, 2-F, 4-F, 5-U, 13-F, 15-F
<i>Melia azedarach</i> L.	261	Cyprus	10-U, 12-P
<i>M. dubia</i> Cav.	286	Australia	3-F, 6-F, 8-F, 9-F, 15-F
<i>Pahudia rhomboidea</i> (Blanco) Prain	44	Philippine Islands	1-F, 2-F
<i>Pericopsis elata</i> (Harms) Van Meeuwen	255	Ghana	1-F, 2-F, 4-F, 13-F, 15-F
<i>Phoebe porosa</i> (Nees & Mart.) Mez	412	Brazil	2-U, 3-U, 6-F
<i>Phytolacca dioica</i> L.	259	Argentina	10-P, 11-P

Species	Hawaii seed lot number	Seed source	Study site number and rating
Pinus brutia Ten.	436	Turkey	6-U, 16-U
	438	Afghanistan	10-F, 11-F
P. canariensis C. Sm.	174	Morocco	16-F
P. caribaea Morelet v. bahamensis Barrett & Golfari	184	Bahama Islands	7-U, 16-P
P. durangensis Martinez	23	Mexico	7-P
	111	Mexico	16-U
P. elliottii Engelm.	52	Georgia	6-P, 7-P
P. engelmannii Carr.	25	Mexico	7-P
P. hartwegii Lindl.	114	Mexico	16-F
P. kesiya Royle ex Gord.	40	Burma	16-F
	163	Viet Nam	5-U, 7-P, 16-P
	188	Thailand	7-P, 16-F
P. occidentalis Sw.	326	Dominican Republic	6-P, 8-F, 9-F, 16-F
	327	Dominican Republic	16-P
P. oocarpa Schiede	32	Mexico	7-U
P. pinaster Ait.	339	Hawaii	16-F
P. rudis Endl.	130	Mexico	16-U
Pithecellobium saman (Jacq.) Benth.	237	Hawaii	1-P, 13-F
	411	Hawaii	12-U
	527	Hawaii	14-F
Pterocarpus echinatus Pers.	5	Philippine Islands	1-P, 2-U, 4-F, 5-U, 6-F, 12-U, 13-U, 15-U
P. indicus Willd.	4	Philippine Islands	4-F
P. santalinus L.f.	332	India	3-F, 6-F
Roseodendron donnell-smithii (Rose) Miranda	272	Puerto Rico	2-F, 10-F, 11-P
	301	Hawaii	13-F, 14-F, 15-F
Serialbizzia acle (Blanco) Kosterm.	102	Philippine Islands	1-U, 13-F
Sindora supa Merr.	43	Philippine Islands	1-U, 2-F, 4-F, 13-U
Swietenia macrophylla King	238	Hawaii	13-U
	336	Belize	2-U, 5-F, 10-F, 11-P
S. macrophylla x mahagoni	445	Virgin Islands	6-F
S. mahagoni (L.) Jacq.	221	Hawaii	1-P, 15-F
	258	Hawaii	1-P

Species	Hawaii seed lot number	Seed source	Study site number and rating
Tabebuia heterophylla (DC.) Britton	211	Trinidad W. I.	6-F
	271	Puerto Rico	2-P, 3-U, 6-F, 8-F, 10-F, 11-U
Taxodium distichum (L.) Rich.	161	Mississippi	2-F
	182	Florida	8-F
Tectona grandis L. f.	164	Malaya	1-P, 2-U
	386	Peru	6-F
	406	New Britain	5-U, 8-F, 9-F, 10-U, 11-P, 12-P
	418	Costa Rica	14-U
Terminalia ivorensis A. Chev.	180	Ghana	2-F, 4-U, 6-F, 9-F
	204	Nigeria	2-U, 13-U
T. superba Engl. & Diels	80	Nigeria	13-F
	179	Ghana	1-U, 2-F, 4-F
Tetraclinis articulata (Vahl) Mast.	168	Tunisia	7-F, 8-F, 10-U, 11-P, 12-P
Thespesia populnea (L.) Soland. ex Corr.	448	Hawaii	10-U, 11-P
Tieghemella heckelii Pierre ex Cheval.	181	Nigeria	2-F
Toona ciliata Roem. var. australis (F.v.M.) C. DC.	362	Hawaii	13-F
Tristania conferta R. Br.	346	Hawaii	7-F, 8-F, 9-U, 10-F, 11-U
	410	Hawaii	12-F

Table 18--Classification of the planting site soil series in four systems^{1/}

Island	Site number	Soil series	U. S. Soil Taxonomy subgroup and family ^{2/}	U. S. Systems of 1938 Great Soil Group ^{3/}	FAO/UNESCO legend ^{4/}	French soil classification subgroup ^{5/}
Hawaii	1	Malama	Typic Tropofolists dysic, isohyperthermic	Lithosols	Dystric Histosols	II/212
Hawaii	2	Honokaa	Typic Hydrandepts	Hydrol Humic Latosols	Ochric Andosols	IV/221
Hawaii	3,4	Kiloea	Thixotropic, isothermic	Lithosols	Dystric Histosols	II/212
Maui	5	Kailua	Typic Tropofolists dysic, isothermic	Humic Latosols	Ochric Andosols	IV/221
Maui	6	Olinda	Typic Hydrandepts thixotropic, isothermic	Latosolic Brown Forest Soils	Humic Andosols	IV/221
Maui	7	Laumaia	Entic Dystrandepts medial, isomesic	Latosolic Brown Forest Soils	Humic Andosols	IV/222
Molokai	8	Olelo	Typic Dystrandepts medial, isomesic	Humic Ferruginous Latosols	Humic Acrisols	X/231
Molokai	9	Kahanui	Humoxic Tropohumults clayey, oxidic, isothermic	Humic Ferruginous Latosols	Humic Ferralsols	X/313
Oahu	10,11	Lualualei	Petroferric Acrohumox clayey, ferritic, isothermic	Dark Magnesium Clays	Chromic Vertisols	III/111
Oahu	12	Ewa	Typic Chromusterts very fine, montmorillonitic, isohyperthermic	Low Humic Latosols	Haplic Phaeozems	VI/412
Kauai	13,14	Hanamaulu	Torroxic Haplustolls fine, kaolinitic, isohyperthermic	Humic Latosols	Humic Ferralsols	X/241
Kauai	15	Halii	Tropeptic Umbriorthox clayey, oxidic, isohyperthermic	Humic Latosols	Humic Ferralsols	X/322
Kauai	16	Mahana	Typic Gibbsiumox clayey, ferritic, isothermic	Humic Ferruginous Latosols	Humic Ferralsols	X/321

1/ Adapted from Beinroth, Ikawa, and Uehara (1974). This table should be read from left to right only. It should not be used for general correlations of the different units of the four systems.

2/ McCall 1973.

3/ Cline 1955.

4/ FAO 1970.

5/ Commission de Pédologie et de Cartographie des Sols (1967).

Table 19--Tree species identified as promising in species adaptability trials in Hawaii, 1964-74, for timber (T), protection forests (P), amenity plantings (A), Christmas trees (C), craftwood (Cw) or shade and shelter (S)

Species	Hawaii seed lot number	Study site number	Island	Elevation	Annual rainfall	Uses
				Feet	Inches	
Acacia implexa	19	12	Oahu	580	25-30	A,P,T
A. melanoxylon	1	9	Molokai	3250	50-60	T
	55	3	Hawaii	2060	200	T
Albizia falcata	203	1	Hawaii	100	100	A,T
Araucaria angustifolia	300	2	Hawaii	2100	110	T,A
	364	2	Hawaii	2100	110	T,A
	370	3	Hawaii	2060	200	T
A. columnaris	239	1	Hawaii	100	100	T,A,C
	453	11	Oahu	580	25-30	A,C
	398	2	Hawaii	2100	110	T,C
Callitris endlicheri	330	11	Oahu	580	25-30	A,P,T
	330	12	Oahu	580	25-30	A,P,T
	330	6	Maui	3200	90	T
	439	16	Kauai	2350	35-40	P
Cedrela odorata	144	2	Hawaii	2100	100	T
Chlorophora excelsa	217	12	Oahu	580	25-30	A,P,T
Chukrasia tabularis	331	2	Hawaii	2100	110	T
Cordia alliodora	264	11	Oahu	580	25-30	P,T
C. subcordata	449	11	Oahu	580	25-30	Cw
Eucalyptus botryoides	366	9	Molokai	3250	50-60	T
	366	6	Maui	3200	90	T
E. camaldulensis	245	10	Oahu	250	15-20	A,P,S
	367	11	Oahu	580	25-30	A,P,T
	367	14	Kauai	720	100	T
	367	16	Kauai	2350	35-40	P,T
E. citriodora	246	1	Hawaii	100	100	A,T
E. deglupta	227	2	Hawaii	2100	110	T
	302	15	Kauai	780	116	T
	428	14	Kauai	720	100	T
E. microcorys	318	6	Maui	3200	90	T
E. punctata	368	6	Maui	3200	90	T
	368	16	Kauai	2350	35-40	P,T
E. robusta	290	4	Hawaii	2860	200	T
	322	9	Molokai	3250	50-60	T
E. saligna	345	6	Maui	3200	90	T
	369	6	Maui	3200	90	T
E. sideroxylon	372	6	Maui	3200	90	T
E. tereticornis	373	6	Maui	3200	90	T
Flindersia brayleyana	200	1	Hawaii	100	100	A,T
	219	1	Hawaii	100	100	A,T
	219	2	Hawaii	2100	110	T
	219	4	Hawaii	2860	200	T
Grevillea robusta	225	2	Hawaii	2100	110	A,P,T
Hibiscus elatus	104	1	Hawaii	100	100	A,T
	104	15	Hawaii	780	116	T
	104	2	Hawaii	2100	110	A,T
Liquidambar formosana	279	14	Kauai	720	100	T
	279	15	Kauai	780	116	T
	279	9	Molokai	3250	50-60	T
	279	3	Hawaii	2060	200	T
	324	2	Hawaii	2100	110	A
	325	2	Hawaii	2100	110	A
Melia azedarach	261	12	Oahu	580	25-30	A,P
Phytolacca dioica	259	10	Oahu	250	15-20	P,S
	259	11	Oahu	580	25-30	A,P,S
Pinus caribaea v. bahamensis	184	16	Kauai	2350	35-40	P,T
P. durangensis	23	7	Maui	6360	40	P,T
P. elliotii	52	6	Maui	3200	90	T
	52	7	Maui	6360	40	P,T
P. engelmannii	25	7	Maui	6360	40	P,T
P. kesiya	163	7	Maui	6360	40	P,T
	163	16	Kauai	2350	35-40	P,T
	188	7	Maui	6360	40	P,T
P. occidentalis	326	6	Maui	3200	90	T
	327	16	Kauai	2350	35-40	P,T
Pithecellobium saman	237	1	Hawaii	100	100	A,T
Pterocarpus echinatus	5	1	Hawaii	100	100	A,T
Roseodendron donnell-smithii	272	11	Oahu	580	25-30	A
Swietenia macrophylla	336	11	Oahu	580	25-30	P,T
S. mahagoni	221	1	Hawaii	100	100	A,T
	258	1	Hawaii	100	100	A,T
Tabebuia heterophylla	271	2	Hawaii	2100	110	A
Tectona grandis	164	1	Hawaii	100	100	A,T
	406	11	Oahu	580	25-30	P
	406	12	Oahu	580	25-30	P
Tetralclinis articulata	168	11	Oahu	580	25-30	A,P,T
	168	12	Oahu	580	25-30	A,P,T
Thespesia populnea	448	11	Oahu	580	25-30	Cw

Whitesell, Craig D., and Gerald A. Walters

1976. **Species adaptability trials for man-made forests in Hawaii.** USDA Forest Serv. Res. Paper PSW-118, 30 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The performance of 90 species, mostly from the tropics and subtropics, was appraised in field trials for 5 years. Planting sites ranged from near sea level to 6360 feet (1940 m) elevation; rainfall from less than 20 inches to more than 200 inches (500 to 5000 mm); and soils from thin mucks overlaying lava rock to deep, highly leached latosols. Thirty-two hardwoods and 10 conifers were rated as promising for either timber production, watershed production, erosion control, or amenity plantings. Fourteen are native to Australia, and are eucalypts. Few of the high quality timber species tested proved well adapted, with low soil fertility the primary limiting factor. Very few trees died from disease or insect attack.

Oxford: 232.11:(969).

Retrieval Terms: species trials; Hawaii.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

FIRE AND CHILDREN: LEARNING SURVIVAL SKILLS

Jeanne H. Block Jack Block William S. Folkman



CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Methods	4
Results	5
Nature of Fire Experiences and Interest	5
Analysis of Mothers' Behavior	6
Analysis of Children's Behavior	7
Other Experimental Procedures	9
Discussion and Implications	10
Appendix	13
Literature Cited	14

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SUMMARY

Block, Jeanne H., Jack Block, and William S. Folkman.

1976. **Fire and children: learning survival skills.** USDA Forest Serv.
Res. Paper PSW-119, 14 p. Pacific Southwest Forest and Range
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Oxford: 431.3:UDC159.922.7

Retrieval Terms: children-caused fires; fire prevention; fire safety;
personality characteristics.

Five and 6-year-old children attending school at the Harold E. Jones Child Study Center of the University of California, Berkeley, were studied to assess their competence in potentially hazardous situations—the specific focus was on fire hazards. This work was an extension of a more extended, longitudinal study of cognitive competence and social-emotional competence. Base data were available on these children from the time they entered the school at the age of 3.

The study was designed . . .

1. To amass information from a number of essentially normal, healthy young children about their interest in, anxieties about, attitudes toward, and reactions to fire.

2. To study the relationship of particular personality characteristics of these children to their attitudes about and performance with potentially hazardous fire material.

3. To assess the socialization techniques and teaching strategies used by mothers in standardized learning situations involving the controlled use of fire materials.

4. To evaluate the relationship of particular techniques used by mothers and their attitudes about fire to the child's perceived attitudes about and observed performance with fire materials.

Wide individual differences in attitudes about fire were found, despite the young age, the relative homogeneity, and the small size of the sample available for study. However, this research is not offered as a final definitive exposition for a particular theory of childhood fire-setting behavior. Its primary value is in suggesting hypotheses for further study in this complex problem area. It does have implications for modifying prevention programs of fire protection agencies.

Five generalizations about children's attitudes toward and behavior with fire are suggested by the findings:

1. Attitudes of boys are markedly different from those of girls. Boys are more interested in fire, have

more fantasies about it, and are more frequently involved in fire play. Girls appear to be more fearful of fire, and, for a variety of possible reasons, are less likely to be interested in experimenting with fire materials;

2. Fire assumes increasing salience for children between the ages of 3 and 6 years. Interest in fire is greater at an earlier age than often has been assumed;

3. No racial differences were observed in terms of children's competency in handling of fire materials, caution with fire, fear of fire, engagement in fire play, or in accident histories;

4. Fire play is associated with undercontrol of impulse (i.e., impulsiveness, inability to delay gratification, taking risks) and inability to modify one's level of impulse control in accordance with the demands of the situation;

5. Wide individual differences were found in the extent and nature of the training children were given on the use and dangers of fire materials.

The findings of the study suggest that fire play in very young children is common and should be viewed more as a function of curious, exploratory play than as a function of psychologically driven, psychopathological behavior as might be true of fire-setting by older children.

We found similarities between personality characteristics of children who are more frequently involved in accidents and those showing a keen interest in fire, both with respect to the frequency of exposure to hazards and a lesser ability to cope with hazards encountered. This relationship suggests that methods used in accident prevention may be adaptable to fire prevention efforts.

Parental methods of handling children's interest in fire have implication for fire prevention efforts. Some children keenly interested in fire had been prohibited from touching fire materials; some children most competent in handling fire had been allowed and even encouraged to use fire materials under parental supervision. These observations suggest that prevention ef-

forts might better be directed towards improving ability to cope with environmental hazards rather than toward reducing exposure to risks through prohibitions. Such programs would be aimed at helping the child develop competence in handling potentially dangerous materials (or situations) at times that are appropriate to his or her developmental level.

Parents have had little help in understanding the process by which children learn to develop skills in recognizing and dealing with potentially dangerous situations. Consequently, they adopt means of varying degrees of effectiveness. Many are particularly lax about teaching their children about fire—more than one of every four parents made no attempt to fulfill this responsibility. Parents who are unsure of how to teach their children safety skills would benefit from being shown alternative methods from which they might select a method suitable to the particular needs of their child and one that would be compatible with their own needs and capabilities. There are many dif-

ficulties in effectively providing such help to parents. A training film for parents illustrating various possible teaching strategies is suggested.

In the search for specific training strategies, we should not lose sight of other parental child-rearing characteristics that were found in this study to be associated with the development of competence in handling fire materials. Parental child-rearing practices that encourage the assumption of responsibility; promote independence in the child; and encourage rational decisionmaking in the context of clear parental expectations, respect, and caring for the child may be expected to promote the development of ego structures in the child that will both benefit growth and minimize play with fire.

Another general implication of the results of this study suggests that educational programs need to be instituted early in a child's life. By the age of 5, many young children are already interested in and experimenting with fire.

Much of the fire prevention effort of natural resource management agencies is directed at children. This emphasis is based on several sound reasons. First of all, and most obviously, children are responsible for a significant, and growing, proportion of all wildfires. Second, and more importantly, the patterns of carelessness or cautiousness, indifference or concern that people establish as children will largely determine the way in which they will relate to fire as adults.

An earlier study revealed some of the factors associated with children-caused fires (Folkman 1966). This work stimulated the development and testing of conservation fire prevention educational materials and programs for use with early elementary school children (Gladden and Carlin 1970, Folkman and Taylor 1972, Gladden¹). An exploratory study of children with a history of fire setting provided insight into the personalities and backgrounds of such fire-problem children (Siegelman and Folkman 1971). However, the chronic fire-setter is responsible for but a small proportion of all children-caused fires. The bulk of such fires appears to be started by single offenders—primarily young boys who are expressing an almost universal interest in fire. No one appears to have given attention to how apparently normal boys learn to deal with fire in their lives and avoid misadventures with it. This study seeks to rectify this gap in our knowledge.

This paper summarizes the reports of a study² of 5- and 6-year-old children and their interest in, anxieties about, attitudes toward, and reactions to fire. The behavior of both the children and the mothers was analyzed. The findings have implications for fire-prevention programs.

¹ Gladden, Frank H. 1973. *The final report for the elementary school individualized instructional materials research and development program in conservation and fire prevention education 1971-1973*. (Unpublished report on file, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.)

² Block, Jeanne, and Jack Block. 1975. *Fire and young children: a study of attitudes, behaviors, and maternal teaching strategies*. (Unpublished report on file, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.)

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Studies of competence in young children have been focused almost exclusively on two types of competence: cognitive, and social or interpersonal. Little research has been done on the child's competence in potentially hazardous situations. In such contexts, both the cognitive abilities to perceive risk and anticipate consequences and the personality attributes associated with the ability to control impulse and to cope with stress are involved. Accordingly, one of the primary aims of this study was to assess this aspect of competence—the child's ability to deal with hazardous situations.

Similarly, previous research on teaching strategies used by mothers has been limited exclusively to situations in which the parent attempted to help the child with problem-solving tasks. However, much tutoring of young children necessarily involves the teaching of survival skills, and little is known about the processes whereby children are taught to develop respect for and skill in dealing with potentially dangerous situations.

Specifically, the purposes of the research were to:

- Amass information from a number of essentially normal, healthy young children about their interest in, anxieties about, attitudes toward, and reactions to fire;
- Study the relationship of particular personality characteristics of these children to their attitudes about and performance with potentially hazardous fire materials;
- Assess the socialization techniques and teaching strategies used by mothers in standardized learning situations involving the controlled use of fire materials; and
- Evaluate the relationship of particular maternal techniques and attitudes about fire to the child's perceived attitudes about and observed performance with fire materials.

Two variables, central to the larger longitudinal study of personality and cognitive development in young children, appear to be important dimensions related to children's caution or carelessness in the face of fire. These are *ego-control* and *ego-resiliency*. Ego-control relates to the ability to constrain impulse. The child who lacks ego-control tends to be impulsive, cannot delay gratification, is more inclined to take risks, and is more expressive than children who may be overly restraining of impulse. In the present research context, we predicted that children who are more undercontrolling of impulse would be less cautious in their handling of fire materials and would have engaged in more fire play.

The second dimension, ego-resiliency, reflects the child's ability to modify his or her conventional level of impulse control in accordance with the demands of the situation. In this study, the ego-resilient child was expected to exercise greater precaution in the handling of fire materials, to check safety, and to

maintain integrated, competent performance during the experimental situation.

The children's ego-control and ego-resiliency at age 3 and at age 4 were measured by teachers as part of the longitudinal study using the California Child Q Set (CCQ).³

METHODS

The children studied were attending the Harold E. Jones Child Study Center of the University of California, Berkeley. The sample included all 5-year-old boys (18 in all), and all 6-year-old children (14 boys, 15 girls), attending the Child Study Center nursery school. The decision to over-represent boys was based on evidence from earlier studies of clear sex differences in fire-related behaviors. Girls were included in the 6-year-old study group in order to examine the attitudinal and behavioral differences between boys and girls in fire related tasks.

The study-group is heterogeneous with respect to racial and ethnic origins and educational and socioeconomic levels of parents, although it is skewed toward the upper middle class. As part of the ongoing longitudinal study of ego and cognitive development, detailed assessments had been accumulated for each child from the time he or she entered the school at about age 3. The children had been assessed periodically by means of game-like tests in standardized but natural situations, standardized tests, observations in open-field settings, and teacher evaluations. Parents and home situations had also been assessed.

To add to these data from the base study, we interviewed in depth the mothers of children in the fire study about their children's health, developmental, illness, and accident histories. Specific questions were addressed to the children's interests in and actual experience with fire. Methods used by parents in teaching their children about fire were explored. The Q-sort technique (a scaling method used to obtain a picture of the individual's own view of, or attitude toward, the object being considered) was used to quantify behaviors observed in the teaching situation.

Three methods were used to obtain additional data from the children to provide information about their attitudes and reactions to fire. The first method was a modification of a projective test previously used in the longitudinal study in which each child reacts to a standard series of pictures. For purposes of the fire study, two additional pictures representing fire scenes

were developed and included in the series. This test was designed to reflect developmental status in the emotional sphere. The second method was to administer a test to each child (also previously used in the longitudinal study) by asking him or her to enumerate "all the things that children sometimes do that are bad." This test was included in order to examine the relationship between the child's understanding of prohibited activities and behaviors vis-a-vis fire. The third method was to have each child take part in a marble guessing game that assessed the tendency to make premature judgments or to take risks.

Finally, each mother was observed as she taught her child three fire-related tasks—lighting candles on a birthday cake, boiling water on a camp stove, and using sealing wax. Specific instructions were given the mother while the child played in an adjacent room. The mother was told that the situation was purposely left rather open so that she could decide how best to proceed with her child. It was stressed that we were interested in seeing some of the many ways that different parents develop when they try to teach their children to do something safely.

After the home visit, the experimenter codified her observations and impressions of the home and neighborhood environment in which the child was living by completing a 59-item Q-sort pertaining to environmental qualities, including such dimensions as presence or absence of hazards about the home, the child-centeredness of the home, the presence or absence of clutter, and opportunities for outdoor play. It was anticipated that a systematic description of the home situation might provide additional background data relating to both the behavior of the mother in the fire tasks as well as the fire-relevant attitude and behavior of the child.

³ Block, J. H., and J. Block. *The California child Q set: a procedure for describing personological characteristics of children*. 1969. (Unpublished report on file, Department of Psychology, University of California, Berkeley.)

RESULTS

Nature of Fire Experiences and Interest

Base line data concerning the incidence of fire play, burns, fears, and salience of fire among relatively healthy, normal young boys and girls were provided by the interviews with mothers and by observed behaviors of their children.

In this study of 47 children with above average IQ's (mean = 116.7), mostly intact middle-class families, we had hardly expected to find a high incidence of fire setting. And yet we found that two boys had been involved in agency-documented fire play. Additionally, the brothers of three girls included in the study were reported to have also been involved in fire play.

The information available from this study probably underestimates the "true" incidence of fire play. Much fire play undoubtedly goes undetected and, therefore unreported. Further, these children do not represent a "high risk" group, differing as they do in demographic characteristics, and health and emotional histories from those of fire setters in earlier studies.

Eight of the children in the study had suffered burns serious enough to require medical attention. None of these were the result of play with fire, however. Eight children—six girls and two boys—were described by their mothers as having considerable fear of fire. One child had been seriously burned at an early age, and four children had siblings or other relatives who had been burned (three as a result of clothing catching on fire from a fireplace). A relative of another child had been a fire setter and the child was experiencing nightmares about fire. Mothers of the two remaining children could not account for their children's strong fears of fire.

Interest in fire, reflected, for example, in requests to light matches or in playing with fire materials without permission, was significantly higher among boys than among girls according to report of mothers (59.4 percent, compared to 33.3 percent, respectively). Few mothers were concerned about the fire interest of their children. None of the mothers of girls and only 18.8 percent of the mothers of boys said they were worried about their child's interest in fire. The feeling was commonly expressed that interest in fire was a phase of normal development that would soon be outgrown.

When asked how they attempted to handle the

child's interest in fire, the largest number of mothers indicated that they provided opportunities for the child to use fire materials under supervision in lighting fires in the fireplace, building campfires, lighting candles, and similar activities. Talking with the child about fire—explaining its dangers—was the next more frequent method mentioned. Four mothers indicated that they expressly forbade their children to play with fire.

The most common responses to the question "What is the most important thing you want your child to learn about fire?" were:

Response:	Percent Reporting
The dangers of fire	38.8
The importance of learning how to handle fire safely and competently	23.0
The importance of staying away from fire altogether	13.0

Some mothers tried to impress their children with both the dangers of fire and the importance of developing competence. Interestingly, five mothers of boys, whom they had described as interested in fire, reported that they had never really talked with their sons about fire. For the total sample of children, including children who were reported as never having shown an interest in fire, 13 mothers (27.6 percent) reported that neither parent had discussed fire or attempted to show their child how to use fire materials. They either thought it unnecessary or had never given it any thought.

The salience of fire in the thinking of the children was evaluated in two ways. First, by reference to the results of the Conceptions of Badness inquiry wherein the subjects were asked to enumerate prohibitions that children sometimes violated. This enumeration showed an increased mention of fire with age. (This procedure had been included in the test batteries of the longitudinal study of children at ages 3, 4, and 5 as well as having been administered to the subsample of children participating in the Fire Study.) The percentages of children of various ages mentioning fire as "bad" were:

Age of child:	Percent Reporting
3 years old (N=118)	2.5
4 years old (N=128)	5.5
5 years old (N= 85)	14.1
5 and 6 years old (Fire Study children) (N= 47)	21.3

Although this test was administered to the Fire Study children before their participation in the fire tests, the presence of the experimenter's fire extinguisher may have influenced the number of references to fire play among this subsample.

Sex differences in the salience of fire are reflected in the preponderance of boys listing fire play; 77 percent of those mentioning fire were boys.

Another indicator of the salience of fire among pre-school children is the frequency of fire themes in free play. Records of clinician's observations of a 20-minute structured free-play situation from the longitudinal study were examined to determine the incidence of fantasy play regarding fire. All of the children playing out themes of fire were boys. The protocols describing this play revealed this distribution by age:

Age of child:	Percent Reporting
3 year olds	2.6
4 year olds	12.5
5 year olds	11.4

On the basis of mothers' interview responses in the Fire Study regarding preferred activities of their children, we found that a preference for fantasy play was significantly related to fire interest ($r = .31$; $p < .05$). This relationship suggests that dramatic play may be a way of coping with the fascination fire holds for some children. That anxiety may underline play concerned with fire is implied by the content of such play. Responses in the test situations and mothers' interviews suggest that anxiety is an important component in the child's perception of fire.

Analysis of Mothers' Behavior

Three measures were used in this study to assess mothers' behavior. Scores on two dimensions were derived from observations of the mothers during the fire task teaching situation: (1) The *Maternal Caution* score reflects the safety precautions taken by the mother in her handling of the fire materials, and (2) the *Explanation* score reflects the explanations of specific measures made to the child by the mother. Only the 41 mothers participating in the fire tasks have scores on these variables. The third independent variable, *Supervised Training*, is a composite score based on responses by all 47 mothers. This score reflects the reported explicit attempts on the part of parents to teach their child to use fire materials in a safe manner, i.e., teaching the child how to light

matches, to help build fires in the fireplace, to help with campfires.

Those scoring high and low (above and below the median) on these independent variables were evaluated systematically against nine data sources comprising the dependent variables (see Appendix).

Mean scores of the two groups, the t values, and indications of the significance of the differences between means were computed. Probability levels were based on two-tailed tests of significance, except in a few instances when not appropriate. Items significant at or beyond the 10 percent level of probability were included because of the possibility of comparing results with overlapping but independent data sources. Assertions that groups *do not differ* on particular characteristics are based on t values less than 1.00. Indications in the text that two groups *tend* to differ are based on t values greater than 1 but less than the 1.69 required for significance at the 10 percent level, given the degrees of freedom available.

Explanation—Mothers providing their children with more explanations and reasons during the fire tasks did not differ in educational levels achieved from those who scored low on this dimension. This was true of the spouses, as well. Age, sex, and IQ distributions of the children were also similar in both groups. Mothers providing more explanation did have higher socio-economic status ratings than did mothers in the low scoring group. Mothers in the high group reported providing more supervised training in use of fire materials. Similarities between high scoring mothers in the fire study and those who provided explanations and rationales for their children in the cognitive training tasks of the longitudinal study suggest some generality of teaching styles across the two different types of situations. Observers in describing both groups of mothers as effective teachers used such terms as clear and coherent, patient, supportive, encouraging their children to proceed independently. These mothers appeared relaxed, spontaneous, and resourceful. They, and their spouses, appear to have developed a clear set of standards for themselves and their children. However, despite differences in child-rearing orientation, teaching styles, and environmental concepts, the children of high and low scoring mothers were not seen as differing either in their personality characteristics or in their behaviors with regard to fire.

Supervised Experience—This division was based on the responses of mothers to questions about the amount and nature of explicit training they provided their children in the use of fire materials. In both the

high and low scoring groups, no difference in the age or sex distribution of the children were found. The educational level of the fathers and the socio-economic ratings of the families were also equivalent. High-scoring mothers tended to be better educated. The high group had significantly fewer minority group families, and the IQs of the children were higher (120 vs. 112 for the high and low groups respectively; $p < .05$).

Mothers who reported having emphasized fire training in the home appeared to perceive their training as successful. They appeared to have confidence in their children and allowed them to proceed independently in the fire tasks. Mothers who had not emphasized fire training in the home were observed to be more active in their teaching. They were more talkative, dramatized their teaching, and seemed to get into more power struggles with their children. The descriptions by nursery school teachers of the children who received explicit training at home in handling fire materials indicate that the children were considered reasonable, curious, outgoing, expressive, and socially comfortable. In families placing less emphasis on fire training, the fathers reported greater concern about the welfare of their children, and worried more about their health and their future. They appeared to make fewer demands on their children. It would appear that in their attempts to protect their children, parents in the low Supervised Experience group are reluctant to expose them to potentially hazardous situations—even under close parental supervision.

Maternal Caution—Only a few significant differences emerged from the comparisons of mothers scoring high and those scoring low on the Maternal Caution variable. Although maternal caution appears to be consistent across the three fire tasks and shows some relationship to cautiousness of the child in handling fire, it does not seem to predict behaviors of either mother or child in other settings.

Analysis of Children's Behavior

Five summary scores derived from the coded responses in the mothers' interviews and one obtained from the observation of the children's behavior during the fire tasks were used in analyzing the behavior of children with fire:

1. *Child's interest in fire.* Reflects the mother's perception of her child's interest in fire as expressed in play with fire, requests to light fires, talking about fire, or similar behavior.

2. *Child's fear of fire.* Reflects the mother's

perception of her child's fear of fire as expressed verbally or in active avoidance of situations in which fire is involved.

3. *Fire competence.* Reflects the child's competence in using fire materials as related by mother.

4. *Fire play.* Reflects the documented participation of the child in play with fire.

5. *Accident liability.* Reflects the extent to which the child has been involved in accidents resulting in broken limbs, serious cuts, burns, contusions, or similar injuries.

The item derived from observation of the children's behavior during the performance of the fire tasks was the Child's Caution score. This reflected the safety precautions exercised by the child in those cases where he or she was allowed personally to handle the fire materials (only 15 children were so permitted).

Fire Caution—There were no significant differences in demographic characteristics between the high and low groups of children. The two groups were equivalent in age, IQ, race, and sex compositions. There were no significant differences in the educational levels of the two groups of fathers nor in the socio-economic status of the families. Mothers of the children in the high Caution group tended to be better educated.

Cautious children appear to be more controlled, submissive, and docile and come from homes where they are more closely supervised than do children in the low scoring group. Their mothers also appear to be more inhibited and controlled. Caution in the fire tasks appears to generalize to other areas of experience, independently assessed, since children scoring high on caution also were described by their nursery school teachers as docile, undemanding in interpersonal situations, and more controlling of impulse expression.

The two children with a history of documented fire play were represented in the low caution group.

Competency in Handling Fire—The high and low groups did not differ with respect to age of children, racial composition, or in the educational levels attained by fathers and mothers. The high Competency group tended to have higher socio-economic ratings. Only boys were represented in the high group ($p < .05$), and the IQs tended to be higher for children in the high group ($p < .10$).

Mothers of children who are described as competent in their handling of fire materials appear to respect the competence of their children and to allow them to proceed independently. Fathers of children in this group place greater emphasis on the achieve-

ments of their children, and both parents seem relatively free of anxiety about their children. The children in the high group appear more controlled, being described as less expressive, active, and responsive than their peers in the Low Competency group. The latter were said to be more easily offended and to behave in accordance with the sex stereotypes of our society.

Competence in this context did not derive from more explicit, supervised training in the use of fire, but appeared to develop as a result of parentally encouraged independent experimentation in the home. These boys were perceived as generally competent in a wide range of situations, bright, trustworthy, and concerned with their own safety.

Fear of Fire—Comparisons on this variable are between eight children who were said by their mothers to have strong fears about fires and the other children. The two groups did not differ in terms of age, race, intelligence, or in fathers' educational levels. There were significantly more girls in the Fear groups (6 of 8; $p < .01$), and the educational levels of mothers in this group tended to be higher. Two of the children in the Fear group elected not to participate in the fire tasks, and one child quit after lighting candles on the birthday cake.

Children who are fearful of fire tend to be girls, have been more frequently burned, are less interested in fire, and tend to withdraw from situations in which fire materials are involved. The more fearful children appear less at ease in new situations and might be characterized as more anxious generally than their less fearful peers. Mothers of these children were described as more controlling in several contexts. However, the relatively few differences characterizing the mothers, fathers, or environmental contexts of the more or less fearful children suggest that fears of fire may have developed from a greater number of unfortunate experiences with fire on the part of the high group.

Fire Interest—Analysis of the demographic data revealed no differences in the educational levels achieved by fathers, in socio-economic ratings, or in the IQs of the children in the high and low Fire Interest groups. Fewer children from minority groups tended to be represented in the high group ($t = 1.42$) and mothers of children in the low group tended to be better educated ($t = 1.21$). As might be expected more boys scored above the median of Fire Interest (79.1 percent and 56.5 percent for the high and low groups, respectively, $p < .10$). Despite the relative homogeneity of the total sample with respect to age, children in the high Fire Interest group were sig-

nificantly younger (mean ages 59.8 and 62.7 months, respectively, $p < .01$).

The results on interest in fire suggest that for most children such interest may be a passing phase, soon outgrown. In addition to age differences, this observation is based on differentiating personality characteristics reflecting lesser maturity rather than psychopathology. The nursery school teachers' protocols describe the high Fire Interest children as more immature, more readily moved to tears, and as preferring nonverbal methods of communication. They were also described as tending to be more easily victimized and stubborn. In contrast, and consistent with their greater age, low Fire Interest children were seen as considerate, emphatic, concerned with fairness, and as tending to be more competent, interesting, and creative.

The items discriminating between mothers in the two groups do not appear, however, to be related to the age differences in the children. Mothers of high Fire Interest children handle them with kid gloves, attempting to avoid confrontations. They make fewer demands, are less emphasizing of achievement, and tend to be less effective teachers. Although fathers of high Fire Interest children appear to have established expectations for their children, these appear more in the area of conformity than in the area of achievement and maturity.

History of Fire Play—Documented evidence of fire play was available for only two boys in the sample. Others may have been similarly involved, but we had no evidence of such play. Obviously, it is hazardous to attach significance to data based on only two instances, but the importance of trying to learn as much as possible about children who have actually played with fire justifies some analysis. None of the demographic variables reliably differentiated the boys with a history of fire play from their complement group. Their combined score on the Undercontrol Index was .23 in contrast to $-.03$, the average for the remainder of the sample. They were observed to be considerably less careful in lighting the candles on the birthday cake. Data from the mothers' interviews revealed that the two boys were provided fewer opportunities for supervised use of fire materials, tended to be punished more often for playing with fire, and were more often burned. The mothers of the Fire Players encouraged independence and autonomy according to their self-reporting of child-rearing attitude. They tended to be less trusting of their sons, but placed relatively more emphasis on achievement than did mothers in the complement group.

Parents of one of the Fire Players are divorced.

This, in itself, would not be notable, were it not seen in the light of findings from other studies (Biller 1971, Biller and Merideth 1975, Siegelman and Folkman 1971).

Personality characterizations by nursery school teachers show the two boys to be more active, competitive, interesting, accepting of their own negative feelings, and more open than those in the complement group. They were also described as being admired by their peers.

Other ratings characterize the Fire Players as distractable, curious, fidgety, and less dependent on adults. Their mothers saw them as more restless and less obedient. All of these differentiating items suggest that the differences center about control of impulse—with the Fire Players more undercontrolling than their peers. In these instances, however, playing with fire does not appear symptomatic of psychopathology. The mothers' willingness to grant their sons autonomy and to allow them latitude increases the probability for such active, curious youngsters, whose spontaneity may limit the anticipation of consequences, that some untoward accident may occur during the childhood period in which the testing of limits is an important theme.

Accident Frequency—From what we have seen thus far in our analysis, interest in fire might be expected among presumably normal children. When a single fire-setting incident is reported during early childhood years it would not appear to be the outgrowth of familial and inter-psychic conflict such as was encountered in an earlier study of children involved in repeated fire setting (Siegelman and Folkman 1971), but has more the characteristics of an accident. In this context, a comparison of children with low accident rates may aid in our understanding of the fire experiences of children. The interviews with mothers provided the accident history of each child. Accidents reported by mothers included burns, broken bones, sprains, cuts requiring stitches, frequent bruises which were sustained as a result of falls, getting too close to hot objects or fires, rough-and-tumble play, and running into the street. Children whose accident rates were above the median were contrasted with those whose rates were below.

No significant differences in demographic and socio-economic characteristics were found when we compared the high and low scoring children. However, when teaching strategies used by the mothers were compared, some differences were detected. Observers found mothers of children scoring high on Accident Frequency to be somewhat undercontrolled in communicating, both physically and orally, with

their children, and in surrendering control of the teaching situation to their children. Mothers of the low-scoring children were described as providing more instruction, giving attention to the cognitive aspects of the teaching tasks, and emphasizing the principles underlying successful performance. These mothers were also seen as enjoying the role of teacher, as being resourceful and—while providing guidance—avoiding intrusiveness. In sum, the principal difference between the two groups of mothers was in task orientation. Mothers in the low Accident Frequency group appeared to take their teaching seriously; the mothers in the high groups tended to be more reactive, expressing their frustrations and disagreements, and allowed their children to assume control of the situation.

The child-rearing practices of mothers whose children scored high on Accident Frequency reflect a disinclination to set limits for their children—they allow their children more autonomy and provide less guidance—an orientation that may increase exposure to potential injury. The reported child-rearing practices of fathers of these children tended to reinforce the practices of their spouses.

Descriptions of the home situations tend to indicate somewhat more concern with organization and harmonious functioning on the part of families in the low Accident Frequency group. The presence of familial conflict was noted in the homes of high scoring children.

Personality descriptions by nursery school teachers, behavior ratings by the experimenters, and mothers' adjective descriptions all produce results consistent with each other and with the index scores on the Undercontrol and resiliency dimensions. Children in the high Accident Frequency group were found to be less able to cope with stress and were more undercontrolling. Such children are more likely to find themselves in situations involving risk. And with their limited ability to handle stress, the probability of injury or accident is great. The implications of these child traits is compounded when they exist in the context of the parental child-rearing practices that encourage autonomy, accept fighting and participation in rough games, and deemphasize supervision and limit-setting.

Other Experimental Procedures

Risk-Taking Behavior—The risk-taking dimension was evaluated by a procedure requiring the child to determine the predominant of two colors of marbles

in an opaque container by extracting, one by one, as many marbles, or as few, deemed necessary for a decision. Three trials were conducted with each child—one with a color ratio of 70/30, the second, 60/40, and the third, 55/45. The measure proved reliable in terms of its psychometric properties, but it was undifferentiating in its correlations with the children's "real-world" risk exposure as defined by experiencing accidents or playing with fire.

Responses to the Little Bear—The responses to the series of pictures depicting Little Bear in a variety of situations—some happy, some sad—were scored in two ways: Number of affective responses, e.g., "Little Bear is looking out the window feeling sad," "Little Bear is afraid," "Little Bear is happy playing," and causal attribution in the case of the picture depicting a forest fire.

Results from other research studies suggest that fire setters are characterized by an impoverished inner life (Siegelman and Folkman 1971). It was expected, therefore, that children showing high interest in fire might also be less introspective, resulting in fewer affective responses to the Little Bear pictures. As expected, children scoring high in Fire Interest, and those identified as having previously been involved in fire play gave significantly fewer affective responses ($p < .05$ and $.02$, respectively, one-tailed test). The high Fire Interest group and the Fire

Players tended *not* to attribute the cause of the forest fire to Little Bear, whereas, unpredictably, children in the Fire Competent group significantly more often attributed the cause to Little Bear ($p < .01$).

Concepts of Badness—It was anticipated that the salience of fire in the lives of children might be revealed by the extent to which they mentioned playing with fire in response to the question "What are things that children sometimes do that are bad?" As reported earlier, this question had been asked of children previously in the longitudinal study at ages 3, 4, and 5. Responses involving fire increased in frequency over the 3-year period. For children participating in the Fire Study, fire play tended to be mentioned more often by children scoring high on Fire Interest in contrast to those scoring low ($p < .09$, one-tailed test); and by children scoring high on Accident Frequency compared to those scoring low ($p < .05$, two-tailed). For all other group combinations, differences between high and low scoring children were not significant.

Parent-Child Similarity—Siegelman and Folkman (1971) reported that boys with multiple fire-setting histories were seen by their mothers as being less similar to their fathers than were boys who had set but one fire. Comparable father-child similarity and mother-child similarity indexes were developed for the boys in this study, but no significant differences among the various criterion groups were found.

DISCUSSION AND IMPLICATIONS

Despite the young age, the relative homogeneity, and small size of the sample available for study, wide individual differences in attitudes about fire were found. In considering the results of this study, it should be recognized that the criterion groups for comparison are small, thus attenuating the possibility of discerning differences. These limitations are alleviated, to some degree at least, by the independence of the data which were collected from several sources, in addition to that of the Fire Study, itself. Conservative methods of data analysis were used to minimize the considerable statistical problem of dealing with all of the multiple comparisons made available by the various independent data sources. Only those results were emphasized which are both statistically significant and supported by a meaningful coherence among the differentiating items across other independent data domains. This research is not offered as definitive support for a particular theory of childhood fire-

setting behavior. Its purpose was to determine the attitudes and behaviors associated with fire in an essentially healthy group of normal children who were unselected for fire-setting behavior. The primary value is in suggesting hypotheses for further study in this complex problem area. However, we cannot refrain from pointing out some of the implications for prevention and education efforts by fire protection agencies.

The findings suggest five generalizations about children's attitudes toward and behavior with fire:

1. There is a decided difference in boys' and girls' attitudes toward fire. Boys are more interested in fire, have more fantasies about it, and are more frequently involved in fire starts. Girls appear to be more fearful of fire, and, for a variety of possible reasons, are less likely to be interested in experimenting with fire materials;

2. Fire assumes increasing salience with age. Over

the ages studied, 3 to 6 years, children showed an increasing interest in fire. Fire interest develops earlier in children than often has been assumed;

3. No racial differences were observed in terms of competency of children in handling fire materials, caution with fire, fear of fire, engagement in fire play, or in accident frequency;

4. Fire play is associated with undercontrol of impulse (i.e., impulsiveness, inability to delay gratification, taking risks) and inability to modify one's level of impulse control in accordance with demands of the situation;

5. The extent and nature of the training given children by parents on the use and dangers of fire materials differ widely.

Parents have had little help in understanding the process by which children learn to develop skills in recognizing and dealing with potentially dangerous situations. Although parents presumably feel responsible for teaching their children survival skills related to avoiding street accidents, drowning, burns, ingesting poisonous substances, and so on, this study reveals that they differ markedly in the amount and nature of the training they provide. They are particularly likely to be lax in teaching their children about the use of fire. Anxieties carried over from their own childhood experiences with fire seem particularly to mediate against the effectiveness of some parents in this type of survival training. Among parents for whom survival training concerning fire was recognized as a necessary part of a child's socialization, a variety of methods were found to have been used.

Some parents conducted a series of "controlled experiments" with their children in which demonstration of the safe use of matches was followed by allowing the child, for example, to light fireplace fires, candles, or parents' cigarettes. Such an approach, obviously, is only effective with children of proven maturity and dependability, since some children may construe permission to light a fire in the parents' presence as blanket permission for unsupervised use of matches. Other parents have discussed fire with their children, describing and illustrating necessary precautions to be taken but not allowing the child to use fire materials, even under supervision. Some parents reported using fear-induction in the attempt to control the child's interest and experimentation with fire, while other parents rely on punishment for this purpose.

In this present study, some mothers indicated that they had tried to discourage fire play and had refused to let their children use matches. Their rules, however, in contrast to those of the mothers of recidivist

fire setters, appeared reasonable, were described matter-of-factly, and were not invested with undue anxiety or emotion.

Comparison of mothers' behavior in teaching cognitive skills (in the longitudinal study) and fire safety skills shows that the basic mother-child relationship is relatively stable, while the specific techniques, strategies, and modes of dealing with the child may differ with the demands of the situation. This difference suggests that parents who are unsure of how to teach their children safety skills would benefit from being exposed to alternative methods of training.

The findings regarding ego-control and ego-resiliency of high and low Fire Interest Children suggest that fire play in very young children should be viewed more as a function of curious, exploratory play than as a function of psychologically driven, psychopathological behavior that is more apt to be causally implicated in the fire-setting of older children. We found similarities between personality characteristics of children with high accident frequencies and those showing a keen interest in fire, both with respect to hazards encountered and the ability to cope with hazards. Methods used in accident prevention, may, therefore, be adaptable to fire prevention efforts.

Intervention efforts on behalf of fire prevention may take many different forms. They may be primarily instructional or they may be directed toward reducing exposure to hazards or toward enhancing the ability to cope with hazards or both. As Mellinger and Manheimer (1967) note in conjunction with accident prevention, there are philosophical issues involved in such decisionmaking since it is possible that our complex modern society overemphasizes control and risk avoidance at the price of spontaneity and creativity. If such be the case, then "prevention efforts might better be directed toward improving the child's ability to cope with environmental hazards rather than toward discouraging otherwise desirable behavior patterns which happen to also increase exposure to hazards" (p. 106). It may be possible, however, to retain the positive personality characteristics that are correlates of risk-taking—curiosity, openness to experience, vitality—and still reduce exposure to hazards if intervention efforts are concerned with helping the child develop the ability to anticipate consequences of potentially dangerous actions. Intervention programs modeled after this possibility would have as their goal helping the child develop competence in handling potentially dangerous materials (or situations) at the developmentally appropriate time.

The curriculum for young children developed by

Spivack and Shure (1974) emphasizes a cognitive approach to the solution of real-life problems. It was designed to encourage children to generate alternative problem solutions and to evaluate the problem consequences of particular actions. This approach, with some modifications, would seem to be appropriate for use in fire prevention efforts with young children. It is particularly sensitive to the concerns raised by Mellinger and Manheimer (1967). Programs oriented to the prohibitions—the “Thou Shalt Nots”—may be less effective, since the curious, exploring, active child—the child most likely to experiment—may well decide to test the rules and to experience the forbidden.

Another general implication of the results of this study suggests that intervention programs might be instituted earlier than has generally been done. By the time they are 5, many young children have become interested in fire and some may have already experimented with it.

The lack of relationship between fire behavior and ethnic and socio-economic backgrounds suggest that fire prevention efforts may be designed to appeal to a wide cross-section of children—different ethnic groups and different socio-economic classes. The development of programs for specific socio-economic or ethnic target groups need not be considered, unless it is on the basis of stimulating greater response, but not because of differences in fire interest.

Finally, the results of the present study suggest that it is important to develop programs for parents. Such programs might encourage parents to include fire training explicitly in their socialization efforts and might suggest alternative methods for helping children develop responsibility about fire. Twenty-six percent of the mothers participating in this study said neither they nor their spouses had attempted to provide fire safety instructions for their children. Considering the over-representation of upper-middle-class and well-educated parents in our sample, this percentage probably underestimates the numbers of parents who do not offer such instruction for their children.

There are, of course, many difficulties in developing effective programs for parents to encourage them to assume more responsibility for training their children in fire safety. One of the means that might be considered is a training film for the parents. This film would alert parents to their responsibilities in this

area of their child's development and bolster their confidence in their ability to deal with it. It would introduce them to illustrations of alternative methods of teaching children about fire, from which they could choose strategies compatible with their, and their children's, individual needs and capabilities. It is imperative that the approach used be based on a realistic conception of their children's maturity and dependability.

Intervention efforts on behalf of fire prevention may take many forms, from a purely instructional approach to attempts to reduce exposure to hazards or to enhance ability to cope with them. Several approaches have been discussed at different points in this report. They may form a core for use in instructional programs designed for parents. These several approaches include:

1. The *Instructional* approach, as represented in the conservation/fire prevention materials developed for Headstart (Folkman and Taylor 1972).

2. The *Generative* approach in which children are asked to anticipate consequences in different situations involving fire and to develop alternative methods of response to such hazardous situations (Spivack and Shure 1974).

3. The *Discussion* approach in which age-appropriate discussions about fire and its consequences take place between parent and child. This method was reported by some parents in the study and is related to some aspects of the Team Teaching used by the California Division of Forestry with school-age children (Goings 1968).

4. The *Controlled Experiment* approach in which parents demonstrate the safe use of fire materials under controlled conditions and then encourage the child to follow parental example under supervision.

In the search for specific training strategies, we should not lose sight of other socialization emphases that were found in this study to be associated with the development of competence in handling fire materials. Parental child-rearing practices that encourage the assumption of responsibility, promote independence in the child, and encourage rational decisionmaking in the context of clear parental expectations, respect, and caring for the child may be expected to promote the development of ego structures in the child that will both benefit growth and minimize play with fire.

APPENDIX

Data sources used in analysis were:

1. Maternal Child-Rearing Practices Reports (CRPR), a set of 91 socialization-relevant items *Q* sorted into seven categories ranging from *Most Salient* or *Descriptive* to *Least Salient* or *Descriptive*. A rectangular distribution was specified with 13 items to be assigned to each of the categories. These descriptive *Q* sorts of socialization attitudes and practices were completed by the mothers when their children were between 3 and 4 years of age (either 2 or 3 years before the collection of data for the present Fire Study).

2. Paternal CRPR *Q*-sort responses, paralleling the procedure used with mothers described above.

3. Maternal Teaching Strategies *Q*-sort descriptions (TSQ), a set of 49 items describing the behaviors of mother, and to a lesser extent, child, in a cognitive teaching situation. Mothers were asked to help their children accomplish four different tasks varying in their demand characteristics. After the tasks were completed, the experimenter and, in some cases, an observer, completed the *Q*-sort using a rectangular seven-step distribution. These data were collected either 1 or 2 years earlier than those in the present study. Of the 49 items in the TSQ set, 43 overlap with those used to describe maternal behaviors in the fire training tasks.

4. California Child *Q*-sort Descriptions (CCA), a 100-item *Q* set completed independently by three of the child's nursery school teachers. The separate descriptions for each child were averaged to form a composite. These data, too, were obtained 1 or 2 years earlier when the children were enrolled in the

nursery school program for 4 year olds.

5. Behavior Ratings, representing the composited description of each child completed independently by the seven experimenters seeing each child during the 4-year-old assessment period.

6. Mothers' Adjective *Q*-Sort Description of Child, based on a set of 42 adjectives sorted by the mother into seven categories with six adjectives being placed at each step. These data were collected after completion of the testing session in the Fire Study.

7. Mothers' Adjective *Q*-Sort Self-Descriptions, using the same set of adjectives, each mother completed a self-description *Q*-sort.

All of the data described in the above sections are completely independent of the data generated by the experimenter conducting the Fire Study. Three data sources depend upon self-report: The Maternal CRPR, the Paternal CRPR, and the Mothers' Adjective Self-Descriptions. The adjective descriptions of the children derive from maternal perceptions. The descriptive personality data are based on the composited ratings of three (CCQ) or more (Behavior Ratings) observers. For approximately half of the mothers participating in the cognitive teaching strategies situation, two observers contributed their impressions via independent *Q* sorts.

Two remaining procedures, completed by the experimenter in the Fire Study, are not independent. These are: (a) the Fire Training *Q*-Sort descriptions (FTQ) describing maternal teaching behaviors, and (b) the Environmental *Q*-Sort Descriptions (EQ) describing the contextual nature of the child's home environment.

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Block, Jeanne H., Jack Block, and William S. Folkman.

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A number of essentially healthy 5- and 6-year old children were studied to determine their interests in, anxieties about, attitudes toward, and reactions to fire. The relationships of particular personality characteristics of the children and the socialization techniques and teaching strategies of the mothers to the children's perceived attitudes about and observed performances with fire materials were determined. The findings suggest that fire play in very young children is common—more a function of curious, exploratory play than a function of psychologically driven, psychopathological behavior as might be true of fire-setting by older children. Similarities were found between personality characteristics of children with high accident rates and those showing a keen interest in fire. Educational programs emphasizing cautious use of fire materials need to be instituted early in a child's life as interest in fire frequently develops by the time he or she is 5 years old.

Oxford: 431.3:UDC159.922.7

Retrieval Terms: children-caused fires; fire prevention; fire safety; personality characteristics.

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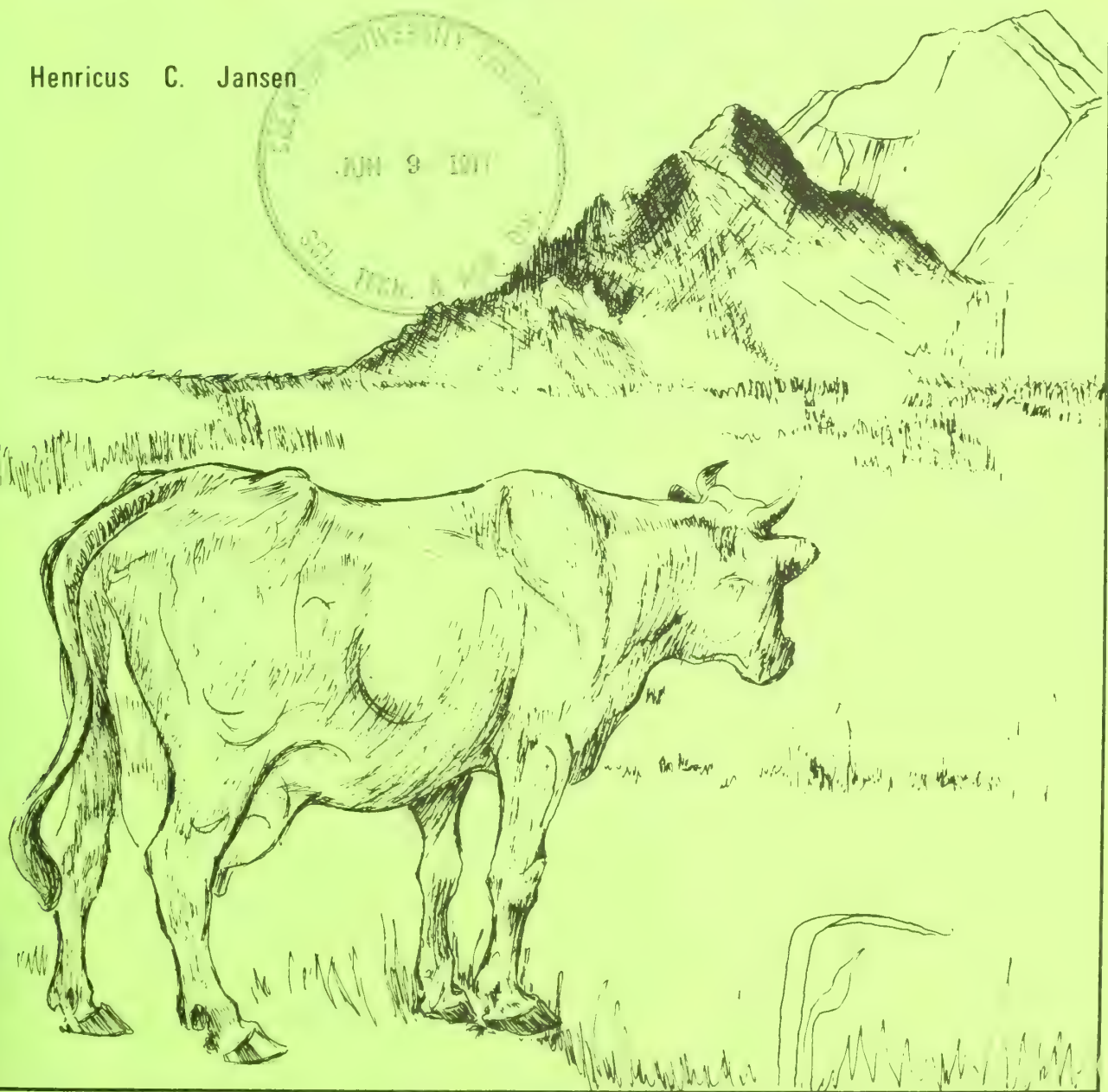
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RANGE RAM ... a long-term planning method for managing grazing lands

Henricus C. Jansen



CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Range Resource Allocation Method	3
Program Components	4
Approach to Planning	5
Assumptions and Limitations	8
Application	9
Planning for Range Resource Management	9
Formulating a Management Plan	10
Selecting a Management Plan	10
Conclusions	11
Appendix	12
A. Activity Formulation with the State Approach	12
B. Calculation of Output Coefficients	14
Literature Cited	15

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SUMMARY

Jansen, Henricus C.

1976. **Range RAM . . . a long-term planning method for managing grazing lands.** USDA Forest Serv. Res. Paper PSW-120, 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 268:624—U681.3.

Retrieval Terms: Timber RAM; range management planning; multiple-use management; linear programming; simulation; computer programs.

Range RAM (Resource Allocation Method) is a computerized planning method that assists with the development of intermediate and long-term management plans for Federal grazing lands. It is applicable to planning problems concerned with spatial and temporal alternatives in allocating resources at forest, district, or lower levels of decisionmaking.

Within a specified planning period, a number of planning intervals are set forth. At the same time a number of management units (resource classes) is specified. The overall condition or "state" of resource classes serves as the analytical focal point of Range RAM. With a state as the starting point for planning, the management potentials and productive capabilities of the resource classes are determined. The range planner specifies maintenance, improvement, and grazing practices (e.g., grazing at specified intensities, spraying, plowing, seeding, water development). These practices are then linked over consecutive intervals and arranged into "management activities" for each resource class. Resource class states may be designated as management targets. Range RAM will schedule practices so that target states are achieved by a date specified by the planner.

For alternative resource and production constraints and management objectives, Range RAM helps the user select an optimum combination of activities and resource classes. Such combinations or problem solutions can be formulated to maximize production of harvestable forage, Animal Months (AM's) of grazing, gross or net revenue, or to mini-

mize the cost of land maintenance and improvement.

Range RAM includes three computer programs—RANGE/MTX (Range RAM Matrix Generator), a linear programming (lp) code, and RANGE/RPT (Range RAM Report Writer). RANGE/MTX is used to generate management activities, calculate the cost and production coefficients associated with generated activities, and construct a resource allocation matrix. The lp code selects an optimum combination of management activities and resource classes for each management objective and calculates the cost of small deviations from this optimal combination. RANGE/RPT generates reports for alternative lp or planner-designed solutions. Reports describe solutions in terms of economic and resource management criteria and list the selected activities in terms of costs, benefits, practices, and scheduled areas within each resource class.

The anticipated application of Range RAM is as a planning tool for resource lands whose primary usage is grazing by either livestock or big game. Other rangeland uses can also be considered, while environmental constraints are recognized explicitly by specifying the type and intensity of range resource development, by reserving forage for other nongrazing purposes, by specifying grazing intensity; and by the temporary or permanent withdrawal of areas from grazing use. In planning for the multiple-use management of the range resource, Range RAM must be used in concert with other appropriate planning techniques.

The U.S. Forest Service manages nearly 106,000,000 acres of rangeland, of which about 58,000,000 acres are classified as suitable for grazing use (U.S. Forest Service 1972). These grazing lands produce an average of 8,000,000 Animal Unit Months (AUM's) per year (U.S. Forest Service 1967-1974). Improved planning techniques to direct management and long-term investment for range rehabilitation could result in an increase in AUM production of more than 80 percent (Forest-Range Task Force 1972, University of Idaho and Pacific Consultants Inc. 1970). Rangelands are characterized by large acreages, diversity in actual and potential production, lack of uniform response to applied management, and slow—often unspectacular—response to improvements.

The development and selection of management plans which show the way to needed increases in AUM production as economically justified expenditures require the efficient allocation of productive resources. Such an allocation process is, however, complicated by conflicting uses of rangeland, by the limited availability of range planning methods, and by the broad spectrum of management options available.

Range Resource Allocation Method (Range RAM) is a computerized method that can help the range planner with the rational allocation of limited resources and with the development of range management and grazing plans. It has been developed for intermediate and long-term planning and decision-making problems typical of Federal grazing lands.

Specific Range RAM objectives are:

- To assist the range planner with the development and evaluation of a wide spectrum of spatial, temporal, and sequential alternatives in the allocation of resources;

- To overcome the computational burden inherent in the formulation of a wide spectrum and large number of such alternatives;

- To assist the range planner with the formulation of "optimum" combinations of management activities;

- To provide for a method of resource allocation that results in the controlled long-term development of the productive capacity of rangelands and the controlled flow of grazing products;

- To assist the range planner with the formulation of alternative management plans for varying management goals, with economic, social, and environmental constraints.

This paper describes Range RAM and outlines the processes of its use. It illustrates the flow of data and information within and between the computer programs, the underlying approach to planning, model assumptions, and the limitations affecting the application of Range RAM. It also provides an explanation of how to use Range RAM, how to formulate a solution, and how to select a management plan from alternative solutions.

Detailed user instructions are beyond the intent and scope of this paper, but may be found in a three-part *Range RAM Users' Manual* which will be available on request from the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, Calif. 94701, Attention: Publications.

Three programs are used in Range RAM: RANGE/MTX (Range RAM Matrix Generator), a linear programming code, and RANGE/RPT (Range RAM Report Writer). To obtain a copy of RANGE/MTX, -/RPT send a 7-track, half-inch tape at least 1200 feet long together with the request to this Station (Attention: Computer Services Librarian).

RANGE RESOURCE ALLOCATION METHOD

The three computer programs that form the basic components of Range RAM provide the range planner with assistance in:

- The development and analysis of a wide spectrum of management activities;

- The formulation and analysis of alternative combinations of management activities, meeting both managerial and resource constraints; and

- The formulation of problem solutions that are optimum in an economic sense and operationally feasible in terms of managerial and other non-

economic criteria (e.g. social, political, environmental).

With Range RAM the planner can formulate solutions for the allocation problem that either maximize production, gross revenue, or net revenue, or minimize the cost of resource management and improvement. Types of information needed for using Range RAM are similar to those needed for any planning process. These include: (a) management objectives and production goals; (b) management, production and budget constraints; (c) present and

potential production capabilities of the land resource; (d) technological means (management practices) available for land management and improvement; (e) anticipated effects of sequences of management and grazing practices upon land resource productivity; (f) financial returns associated with production; and (g) costs of resources used and costs of management.

Range RAM can also be used to (a) evaluate the impact of alternative budgets or production-level requirements on rangeland use, development, and expenditures; or (b) evaluate the impact of alternative range development and use limitations on budget requirements and production levels.

Program Components

The three Range RAM computer programs are RANGE/MTX, a linear programming (lp) code, and RANGE/RPT. RANGE/MTX and RANGE/RPT are written in Fortran IV language for use on the Univac 1108, EXEC 8 computer. ILONA is the lp code that is used in combination with the RANGE programs; however, other lp programs can equally well be used if a computer programmer makes the necessary changes in the RANGE programs. Collectively these programs aid the range planner with three phases of the planning and problem solving procedure: formulation, solution, and interpretation (Fig. 1).

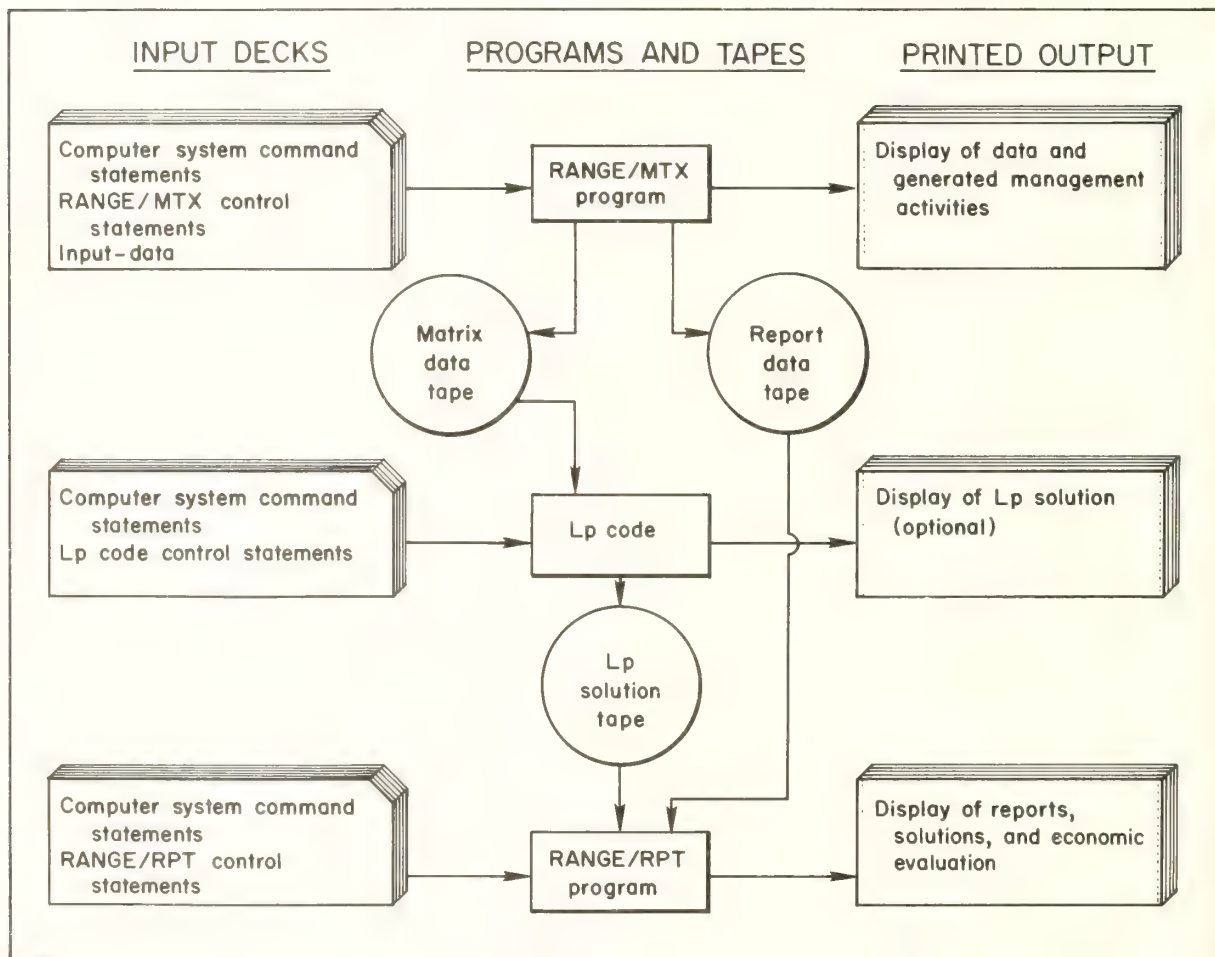


Figure 1—The three input decks activate the RANGE/MTX, the lp, and the RANGE/RPT programs and thereby cause the storage of matrix data, report data, and lp solution data on tape. In addition, these programs cause the display of problem data, lp solutions, and solution reports on computer print-out. Arrows indicate the flow of control information and data.

RANGE/MTX assists in structuring the resource allocation problem into a matrix format that is suitable for subsequent analysis and solution with the lp code. Constituent parts of a problem matrix are: the management activities which allocate the resources used (land and capital) and products obtained, one or more management objectives, and the resource and production constraints.

Principal RANGE/MTX functions are:

1. The input and storage of user-provided data, such as range production characteristics and development potential, improvement and use alternatives, management objectives, and resource and production constraints.

2. The formulation of management activities for range use and development alternatives.

3. The calculation of the cost and production coefficients associated with the formulated activities.

4. The structuring of the problem data into a matrix format.

RANGE/MTX has a number of user-options which generally deal with the specification and manipulation of data, the specification of type and number of alternative objectives of management, and the specification of budget and production constraints. For example, the planner can request for the temporary or permanent storage of his data, control the nature and number of management activities that the program will formulate, and then direct the extent to which computer-calculation of selected production coefficients occurs.

The lp code is a general purpose linear programming optimization routine. Its function is to analyze the resource allocation problem and to obtain possible solutions. Solutions are those combinations of management activities and corresponding acreages which satisfy the constraints of the allocation problem and yield an optimum result.

The RANGE/RPT interprets the lp problem solution and prepares a report. RANGE/RPT output (report) is given in sufficient detail to be understandable to the range planner who is unfamiliar with print-out produced by lp codes.

Two types of reports can be prepared: (a) reports for problem solutions formulated by the lp code, and (b) reports for solutions formulated by the planner. A report describes each activity in the lp solution (or in the planner's solution) in terms of the individual practices (e.g. grazing, improvement, maintenance), the scheduled acreages, the associated costs, and the production levels. The report also gives an economic evaluation of a solution. This includes a description

of the plan's gross and net revenues, costs, production levels and benefit/cost ratios.

Approach to Planning

Long-term planning for range resource use and development must be a well defined and logical process if it is to lead consistently to useful results. Principal steps in long-term planning are:

1. Inventory of the land resource and evaluation of its productive potential.

2. Development of projections for range product demand.

3. Determination of objectives, production goals, and constraining factors.

4. Formulation and evaluation of management activities.

5. Generation of alternative combinations of management activities and their evaluation in terms of management objectives, production goals, and constraining factors.

6. Selection of that combination which best meets most resource and production constraints, which provides for the highest possible value combination, and which is operationally feasible.

While the Range RAM approach considers all of these six steps, the following discussion focuses on the fourth and fifth steps for which the Range RAM programs were specifically designed.

Formulation and Evaluation of Management Activities

We define a management activity as a scheduled sequence of management practices, such as maintenance, development, and grazing practices, extending from the present to the end of the planning horizon. Formulating any number of management activities for a planning unit poses a number of problems which must be resolved. Thus the planner must decide which practices are required to meet management objectives and production goals. He must decide where, when, and in what sequence and combination to apply the selected practices, and determine the extent (area) and the intensity of practice application. Lastly, he must determine the costs, benefits, and effects on the range resource of the practices.

Numerous management activities can generally be formulated for a range resource. The range planner might, for example, plan to graze, control noxious vegetation, and fertilize on one portion of the range resource, while he plans different activities on the remainder. Determining the nature and type, costs and benefits, and intensity and sequencing of the

planned practices in each activity depends on local criteria, conditions, and objectives. Range RAM assists the planner with these tasks.

The range planner starts the process of formulating management activities by selecting a planning horizon for the allocation problem. This planning horizon determines the length of the planning period which the planner must divide into a number (1 to 20) of equal-length planning intervals. An interval may be from 1 to 20 years long.

The rangeland resource determines the dominant characteristics, boundaries, and size of the allocation problem. The planner must divide this range land into a number (1 to 200) of resource classes. Each resource class should, as near as possible, be homogeneous in biological, physical, economic, and management characteristics, and should respond uniformly to management practices.

Next, the planner determines a set of "resource states" and sets of management practices for each of the resource classes. Resource states are descriptions of the resource classes at discrete points in time. Range RAM limits the planner to three characteristics for describing the states of each resource class. With the sets of management practices which have been selected for the resource classes, changes in state must be feasible (e.g., it must be feasible to transform the states of a resource class with the management prac-

tices). The planner should specify as many pairs of related states as possible (i.e., related by a set of practices), including pairs of identical states.

The specific points in time at which resource states must be determined are the beginnings (or ends) of the planning intervals. Any changes in state must, therefore, be accomplished with the specified practices within the length of the interval. The determination of the interval length, the resource states, and the sets of practices to be implemented during the intervals is an iterative process. First, the planner must determine what practices are available. Second, he must determine the length of time needed to complete practice implementation. Third, he must determine the effect of the practices on the characteristics of the range resource.

For each resource class the "initial" state (i.e., the state at the beginning of the planning period or first interval) must also be determined. Naturally, there can be only one initial state per resource class. On the other hand, several states can be designated as the targets for resource class development. Such "target" states can be specified for any one of the intervals in the planning period.

Finally, given all pairs of states and connecting practices for a resource class, a network can be constructed (Fig. 2). A network shows for all intervals in the planning period the specified states and

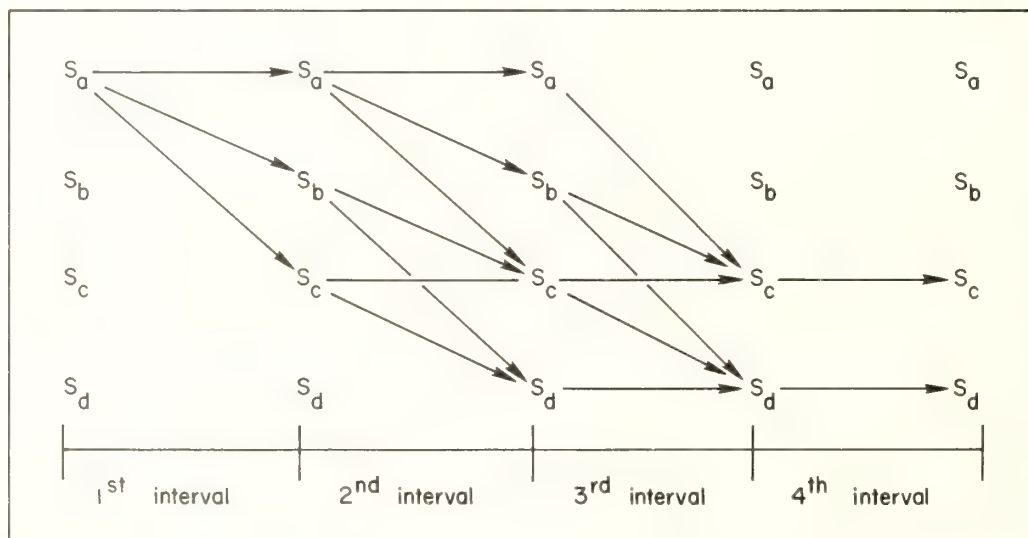


Figure 2—The nodes S_a , S_b , S_c , and S_d in the network represent resource states, the arrows (arcs) connecting the nodes represent sets of management practices (e.g. structural, non-structural, grazing, and maintenance practices). Shown only, are the complete pathways, or Range RAM management activities, which lead from the initial state S_a at the beginning of the first interval, to the target states S_c and S_d at the end of the third interval, to the final states S_c and S_d at the end of the fourth and last interval.

sets of practices. Each complete pathway through the network, leading from the initial state to a target state, to the end of the last interval is by definition a Range RAM management activity and is formulated with RANGE/MTX.

The use of states to monitor and describe the effects of practices on a resource class lends itself to two shorthand notations for describing management activities.

Let a sequence of practices affect a resource class in such a manner as to cause changes in its initial state, say State S_a , leading through intermediate states $S_b, S_c, \dots S_m$ to a final state S_n . Then the shorthand or "state" notation for any management activity can be given as:

$$S_a \rightarrow S_b \rightarrow S_c \dots S_m \rightarrow S_n$$

The state notation is used in RANGE/MTX to identify all possible management activities for each of the resource classes.

The lp code uses an alternative notation. This lp code or "coefficient" notation characterizes the management activities in terms of their costs and benefits on a per unit area per interval basis.

Let the sequence $P_a, P_b, \dots P_m$ represent a scheduled sequence of sets of practices. Let the sequence $C_a, C_b, \dots C_m$ and the sequence $B_a, B_b, \dots B_m$ represent the corresponding sequences of scheduled management costs and benefits. Then in coefficient notation any management activity can be given as:

$$C_a, B_a; C_b, B_b; \dots C_m, B_m.$$

Further detail on the formulation of management activities and on the calculation of benefit coefficients is provided in the Appendix.

Solving the Allocation Problem

Linear programming as a tool for solving resource allocation problems has been applied only to a limited degree in range management. Brown (1961) reported one of the first applications and described a model that uses linear programming as an aid in the valuation of range improvement practices on ranches typical of the Western Range. Nielsen (1964) worked with Brown on the problem of estimating the economic value of the range resource as measured through livestock production. Navon (1969) described a lp model for wildland planning, and Navon (1971) formulated Timber RAM, for commercial timber lands. Kaiser and others (1972) developed the

linear decision model FREPAS (Forest Range Environmental Production Analytical System) which was used by a U.S. Forest Service Forest-Range Task Force for a one-time analysis of selected management alternatives on the nation's forest-range lands. FREPAS was limited to the consideration of only six management alternatives in the formulation of management plans. D'Aquino (1974) and Bartlett and others (1974) described linear models for short-term ranch management activities (resource allocation alternatives). The developed models differ from one another in purpose and in method of formulating the activities.

Range RAM uses linear programming to solve the resource allocation problem. The problem is to find that combination of management activities and acreages that optimizes the management objective function and simultaneously stays within all resource and production constraints. For example, what combination of activities and acreages provides for a least-cost maintenance and improvement program while staying within specified AM-production levels for each planning interval?

The linear programming method used in Range RAM is the revised simplex method. This method has been adequately described in several textbooks dealing with linear programming (Dantzig 1963, Heady and Candler 1958, Spivey 1963) and will therefore not be discussed here.

The resource allocation matrix (*Fig. 3*) that RANGE/MTX generates for subsequent analysis and possible solution by the lp code, contains three types of information: (a) the management activities in coefficient notation; (b) the constraint levels for costs, products, and land; and (c) one or more alternative management objective functions. For a given allocation problem, as defined by the matrix, alternative management options can be analyzed. Each combination of one management objective function and one set of constraints defines an option for which an lp solution may be found. Changes in the matrix (e.g. deletion or addition of management activities or resource classes) define new allocation problems for which again alternative management options may exist.

An lp solution may be "feasible" or "infeasible." It is feasible if a combination of management activities is found that meets all constraints on cost, production, and land. It is infeasible if no combination satisfying all stated constraints can be found. By adjusting one or more of the constraints (i.e. introducing a new management option) the planner may resolve the infeasibility of a solution.

row \ column	one column for each management activity for each of the resource classes		right hand side(s)
input commodity	one row for the management input per unit of area during each planning interval	< or >	input constraints for each interval (minimum and maximum)
output commodities	one row for each output commodity generated from a unit of area during each planning interval	< or >	output production requirements for each commodity for each interval (minimum and maximum)
land	one row for each resource class in the planning unit	$\leq$	total area of land available in each resource class
objectives	alternative management objective(s) considered for optimization	=	final value of objective function(s)

Figure 3—A resource allocation matrix and constraint column (right hand side) for a management problem.

Once a feasible lp solution has been found, a report can be formulated with RANGE/RPT. A report consists of a bundle of activities and their assigned areas (acres, hectares) for all of the resource classes in the allocation problem.

Assumptions and Limitations

The deterministic nature of Range RAM assumes that all management costs, benefits, and commodity prices are fixed and known. Range resource potential, quantitative management goals, and other objectives are assumed to be known with certainty. Also assumed to be known are the range resource production characteristics, expected budgets, state of the art, supplies of fixed resources, and the social, political, and environmental realities.

Because of the limitations of a deterministic model, the planner should judge all results with reservation and update his data and management assumptions frequently when more reliable information becomes available. The planner should regard the quality of Range RAM output as directly related to

the quality of the input provided. The reliability and adequacy of data, the degree to which formulated activities reflect the full spectrum of management opportunities, and the optimality of the formulated solution, are of critical importance in deciding if a proposed solution merits translation into a management plan.

Another set of assumptions and limitations pertains more specifically to the method of formulating management activities. The use of the state approach as an activity-generating method requires that three assumptions are met:

1. The resource classes into which the range resource is divided have uniformity in their physical, biological, and economic characteristics, and in addition each resource class responds uniformly to applied management.
2. The states of all resource classes are known for discrete points in time. Changes in resource states can be accomplished through the application of maintenance, improvement, and grazing practices and occur in a known manner.
3. Unit requirements and unit returns of all prac-

tices or practice combinations are known and can be described in terms of costs and benefits per unit area per unit time.

The use of linear programming as the solution technique requires two additional assumptions: (a) costs and benefits of management activities (as well as their component parts—the practices) are directly proportional to area managed; (b) when several activities are combined to form an “optimum” combination, output per unit of input for each activity remains unchanged, regardless of which other activities are operated within the same or other resource classes.

In order for points (a) and (b) to hold, the standard lp assumptions of linearity, divisibility, and independence of management activities must be made. Point (a) reflects the assumptions of linearity of the production function and divisibility of goods and factors of production. Point (b) involves the assumption of independence among management activities.

The significance of the linearity assumption is that the relationship between costs, benefits, and area is continuous linear, for example, fertilizing 10 acres increases cost and production tenfold as compared to fertilizing 1 acre. The linear relation of cost and

benefit to the area treated reflects both uniformity of treatment and homogeneity of response of the treated area.

The assumption of divisibility implies that all factors used in the production process are considered continuous variables. For example, the practice of constructing livestock watering facilities can in reality only be carried out at discrete unitary levels, but the divisibility assumption includes the construction of, for example, 3.5 water-developments as a possibility.

The assumption of independence of activities may sometimes be unrealistic. Many practices interact and their effect on the final outcome is frequently a function of the other practices carried out on the range resource, simultaneously or at different times. It may, for example, be difficult to formulate an independent management activity containing the practice of fencing. If such an activity were selected in an lp solution for a particular area then the area outside of the fence will generally be affected as well.

Through the careful selection of resource states and practices, the limitations imposed by the assumptions of linearity, divisibility, and independence can be partly overcome. These limitations can be further ameliorated by the procedures discussed below.

APPLICATION

Planning for Range Resource Management

Range RAM serves as a planning technique for lands used mainly for grazing by either livestock or big game. For this reason Range RAM emphasizes and assists with the calculation of the following management costs and benefits:

1. Dollar cost of range maintenance, improvement and utilization (discounted or undiscounted).
2. Harvested forage.
3. Animal months of grazing.
4. Rental fee income derived from livestock grazing (discounted or undiscounted).
5. Net revenue representing the difference between items 4 and 1, above (discounted or undiscounted).

Other concurrent uses of the range can also be analyzed, while constraints on grazing-use of a social, political, or environmental nature are recognized explicitly through the judicious selection of intermediate and target states, the selection of type and intensity of maintenance, improvement and grazing

practices, the reservation of forage for other non-grazing uses, and the withdrawal of areas from grazing-use.

Several computer runs need generally be made to encompass the array of management options available in most situations. For example, the analysis of two options, one with and one without “intensively developed” resource states, must be conducted in separate computer runs. Uncertainty about future levels of product demand, budgets, and prices necessitates the examination of alternative solutions for the same and for different planning problems. Even so, it is extremely unlikely that a globally “optimal” plan will be found.

To a limited extent, Range RAM can assist the planner in developing management plans for range resource uses other than grazing (e.g. timber, water production, recreation). For each alternative use the planner must redefine the resource classes and resource states, since different classification and management criteria will apply. Benefits (e.g., board-feet of timber, acre-feet of water, recreation days) must be calculated by the planner and be entered into the

resource allocation matrix. This is unlike the case for grazing products, where RANGE/MTX calculates output levels and enters these into the allocation matrix.

In planning for the multiple-use management of the range resource, Range RAM must be used in concert with other appropriate planning techniques. Since each Range RAM management objective function can only be defined in terms of a single commodity (e.g. pounds harvested forage, AM's) the optimization of a bundle of commodities is not possible.

Formulating a Management Plan

The complete process of formulating a solution with Range RAM is a three-step procedure (*Fig. 1*). Each step consists of preparing problem specifications, developing a Fortran card deck, and making a computer run.

Step 1: Formulation of the management problem with RANGE/MTX. At this initial step the planner defines his management problem, determines his management data and planning options, and manipulates and stores his data with RANGE/MTX for subsequent analysis. Specific data requirements are the length and number of planning intervals; the resource and production constraints; alternative management objective functions; resource classes; resource states; maintenance, improvement, grazing practices; and cost and benefit coefficients necessary for the valuation of the management activities. All data are then processed with RANGE/MTX and a matrix is prepared. This resource allocation matrix is stored on the "Matrix Data" tape for analysis in Step 2. Problem specifications and the generated management activities are stored on the "Report Data" tape for analysis in Step 3.

Step 2: Solving the resource allocation problem. Information needed for this step comes from the "Matrix Data" tape. The lp code develops solutions for one or more planning options and writes these on the "Lp Solution" tape. Solutions for all alternative planning options form the basis for the reports which are generated next.

Step 3: Formulation of reports with RANGE/RPT. Reports can be prepared for lp, and for user-produced solutions to allocation problems. For the first type of solution, the "Lp Solution" tape and "Report Data" tape provide the necessary data. For the second type, the planner himself must submit part of the required information on Fortran data cards. Additional information is obtained by RANGE/RPT from the "Report Data" tape directly.

The solution and the economic evaluation that are prepared as part of each report consist of a set of tables, schedules, and summaries of the costs and benefits of the selected activities. Costs and benefits are given on a per unit area and on a total area per interval basis. Summaries of costs, benefits and their ratios are given over all intervals and over all activities. Finally, the report gives the value of the optimized objective function and various indices of management performance.

With the three Range RAM programs the planner can process and analyze alternative planning options for the same problem and report on each solution. The three programs can be processed separately, and results can be stored on tape, or the three programs can be processed in one computer job.

Selecting a Management Plan

The process of selecting a solution for implementation as the management plan must be conducted with strict regard to the local situation and competing range resource uses. Ranking of alternative solutions in terms of economic criteria of performance, where possible, is only one of several evaluation and selection procedures. Before considering a solution as a potential management plan, the solution's acceptability must be determined. To be acceptable, a solution must be: feasible, accurate, robust, and practical.

Feasibility of the solution refers to the constraints of the problem. If the lp problem analysis results in an infeasible solution because of limiting constraints, then no acceptable management plan can be formulated from the solution. In this situation the problem must be reformulated until a feasible solution is found. Constraints on cost, production, and acreage need to be reexamined even if a feasible solution is obtained. Uncertainty of budgets, product requirements, and competing resource uses necessitate the analysis of alternative constraint levels. A plan's feasibility must therefore be judged in a context that gives due regard to the local situation and realities.

The accuracy of the solution refers to the costs and benefits of the management activities and to the degree with which the assumptions of the activity formulation process and lp solution procedure are met. The assumption was made that resource classes are homogeneous and react uniformly to management. In assigning the management activities in the solution to the actual "on-the-ground" resource classes, the planner must check carefully if his assumptions live up to reality.

The assumptions of linearity, divisibility, and in-

dependence of the management activities must also be carefully examined. For example, the per unit area cost of management might decrease when larger areas are treated. Since the planner assumed that unit costs and unit benefits are constant and that total costs and total benefits are linearly related to area managed, the linearity assumption may introduce some bias. The costs and benefits of each management activity in a solution must, therefore, be examined for this bias and offending activities should either be adjusted or removed.

“Significant” deviations from the assumptions of divisibility and independence also bias the accuracy of a solution. Depending on the situation, such deviations may increase or decrease the costs and benefits of a plan. Significant deviations include costs or benefits of the management activities that are either too low or too high; the area assigned to certain activities is either too small or too large for effective activity implementation; and activities in one area or resource class affect the costs and benefits of activities scheduled in different areas or resource classes. When deviations from the assumptions of the model are “significant,” the planner can take two alternative courses of action.

One alternative for the planner is to redesign the entire management problem and reprocess all three programs. Another is to delete the unacceptable management activities from the lp solution and reprocess only the RANGE/RPT program with acceptable activities. The first course of action enables the planner to alter the resource classes and their boundaries, to change the resource states and management practices, and to recalculate costs and benefits. The second course of action enables the planner to keep the acceptable management activities and their assigned acres (hectares) in the solution, and to replace the unacceptable part of the solution by a set of activities and allotted areas formulated by the planner himself.

The lp solution for a management problem is

called robust when small changes in cost or benefit coefficients, or small changes in the levels of the resource and production constraints, cause only small changes in the solution and the final value of the objective function. When changes of 5 to 10 percent (depending on the local situation) in cost and benefit coefficients or constraints cause large changes in the lp solution or final objective value, then the solution is not sufficiently robust for translation into a management plan.

The translation of a solution that lacks in robustness involves the risk of misallocating resources. This possibility of resource misallocation provides yet another reason for considering alternative solutions.

A solution's practicality must be viewed in terms of its on-the-ground implementation. When the ranger cannot implement the management activities of a solution, or when their implementation leads to unsurmountable obstacles, the solution is not practical and must be revised.

The examination of a solution's practicality must include an examination of its component parts. Therefore, the planner must check the practicality of timing, location, intensity, and extent of the management practices that are scheduled in the activities. The ranger must be able to carry out proposed grazing practices and grazing systems. Similarly, he must be able to carry out the maintenance and improvement practices for the effective management of vegetation and structural range improvements.

When the planner has determined that a solution is feasible, accurate, robust, and practical, its acceptability should be co-judged by the ranger, grazer, and other range resource users. Judgment should consider and evaluate the possible impact on other resource uses and products, environmental conditions, and other parameters of political and social concern. Much effort can be saved in the formulation and selection of a management plan if all concerned parties partake in the planning process from the start.

CONCLUSIONS

The need for improved planning procedures was documented by the Forest and Rangeland Renewable Resources Planning Act of 1974. By rehabilitating deteriorated land and by adopting improved management practices, range managers have made considerable gains in the past. Shortages and misallocation of capital, time, manpower, and data continue to deter optimum range resource use and improvement programs. Therefore, careful planning procedures and ef-

ficient allocation methods are necessary to ensure wise use of these limited resources.

Range RAM serves the function of assisting the planner with the formulation of management activities and plans. Efficient use of Range RAM facilitates the task of deciding on: the kind of maintenance, improvement, and grazing practices required; where to apply these practices; when best to apply such practices and in what sequence; what level of practice

intensity to employ; to what extent (acres, hectares) practices should be applied; how best to combine practices; and what the associated costs and benefits are.

The quality of Range RAM based plans is directly related to the quality of data and data estimates. The translation of a Range RAM solution into a management plan, therefore, requires much caution. When imprecision of the solution makes its translation into a plan poorly advised, the solution may still be useful as a guideline for choosing alternative management

options or for drawing attention to research needs.

In selecting a Range RAM solution as the management plan, the planner must take into account the financial, legal, social, political, and environmental constraints. The selected management plan is, therefore, not necessarily the economic optimum solution for a resource allocation problem. Instead, it is by necessity a compromise of combining management activities and areas of application so that the result is consistent with all constraints.

APPENDIX

A—Activity Formulation With The State Approach

Each Range RAM management activity is a sequence of practices extending from the present to the planning horizon. The range resource planner selects the horizon and divides the planning period into intervals. Range RAM allows up to 20 intervals of equal length, ranging from 1 to 20 years.

To improve accuracy in activity development, the planner must subdivide and classify the range resource area into resource classes, which should be uniform in biological, physical, economic, and management characteristics. Up to 200 resource classes can be specified per planning problem. Selected classification characteristics may reflect various range features, for example, vegetation type, range condition, productive potential for livestock grazing, or other dominant ecological-environmental features. Given a description of each resource class, the planner must describe the initial states (i.e. the initial set of characteristics) and select and describe sets of intermediate and target states. These states of the resource classes serve as the explicit linkage points in formulating the management activities.

The state of a resource class at the beginning of any interval is a function of: (1) the practices which were implemented during the previous interval, and (2) the previous state. Furthermore, the specific nature of each state delimits the set of maintenance, structural, non-structural, and grazing practices that can be implemented on the resource class during a subsequent interval. Using Range RAM, the planner may describe states with up to three "state parameters." Herbage production, forage production, basal area of merchantable timber, and soil stability are some examples. The planner should exercise managerial judgment, consider concurrent resource uses, and

express planning directives in defining the state parameters most appropriate to each management situation.

Up to nine levels can be specified for each state parameter. For example, the levels for a forage production parameter could be specified as 50, 200 . . . , 1250 lbs/acre/year; for a timber basal area parameter as 500, 1000, . . . , 2000 cft/acre; and for a soil stability parameter as 5 (very poor), 4 (poor), . . . , 1 (excellent). From the set of $9 \times 9 \times 9$ combinations of parameter levels that is theoretically possible for each resource class (each combination represents a resource state), the planner may select a maximum of 15 combinations per resource class. Resource states not included in a given problem because of the specified limit on the number of states may be included and considered for analysis in a subsequent reformulation of the management problem.

As in the selection of the state parameters, the planner should exercise managerial judgment, and express management directives and multiple use criteria in the selection of the parameter levels and resource states. Only those states should be considered which can be achieved with available technology and are acceptable from social, political, and ecological decision criteria. When alternative sets of resource states are analyzed in successive problems, the planner gains the opportunity to determine the relative costs of benefits associated with restrictions on the resource states. For example, the analysis of two alternative management problems—one with and one without "intensively managed" resource states—can be conducted in two different computer runs.

A "state transformation" is the change from one state into another. State transformations may result from natural or man-caused actions. While specifying the resource states, the planner must specify how (i.e. with what grazing, maintenance, structural, and non-

structural improvement practices) the states can be transformed. Furthermore, the planner must determine the costs and benefits of these practices, and must express these on the basis of a unit area and interval.

The range resource manager can use grazing, structural, and non-structural improvement practices for two purposes: first, to increase the production of certain desired benefits; and second, to transform (or maintain, as the case may be) resource states. In situations where dissimilar practices (or combinations of practices) exist which cause identical state transformations, the planner must apply managerial judgment in the selection of one set of practices over the other. For example, under one set of management criteria the use of herbicides might be an acceptable means of transforming a state whereas under another set of criteria these practices must be rejected in favor of prescribed burning.

Control over rate, type and direction of resource class development is generally of great interest to the planner. With the state approach the planner can exercise such control. For each resource class, the planner may specify one or more target states as well as the last planning interval in which these states must be achieved. When no development is planned for a given resource class, the target state should be similar to the initial state. When range resource utilization has a regressive impact, the planner can specify a target state which is less "developed" than the initial state. Rate, type and direction of range resource development can be specified separately for each resource class.

A management activity which has been described in terms of states and practices is best illustrated with a range management example.¹ The general notation is shown here.

Let $\{S_{ijk}\}$ $i = 1, 2, \dots, 9$
 $j = 1, 2, \dots, 9$
 $k = 1, 2, \dots, 9$

identify the set of resource states for a resource class, where i , j , and k identify the state parameters, each having nine levels.

Let $\{P_n\} = (P_1, P_2, P_3, \dots, P_N)$

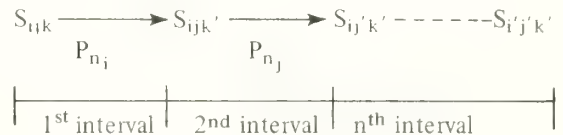
identify the set of maintenance, structural, non-structural, and grazing practices applicable to that resource class. Then in general there exist sub-sets of practices

$$\{P_{n_i}\} = (P_{n_1}, P_{n_2}, \dots, P_{n_l});$$

which when applied to the resource class during an interval transform the states of the set $\{S_{ijk}\}$ into other states of that set, for example:

$$S_{ijk} \xrightarrow{(P_{n_1}, P_{n_2}, \dots)} S_{ijk'}$$

For a sequence of consecutive intervals leading from the present to the planning horizon, a management activity can then be written as follows:



To use RANGE/MTX for activity formulation, the planner must specify the planning horizon, the number of planning intervals within the planning period, one or more resource classes and the area of each. For each resource class he must specify:

1. The resource states (up to fifteen per resource class);
2. The initial state;
3. One or more target states;
4. The state transformations;
5. The sets of management practices with which state transformations are accomplished;
6. The interval in which target states must be achieved; and
7. The inputs required and benefits produced during the state transformations.

Following their formulation, all management activities are entered into the resource allocation matrix. The planner provides the cost and production constraint levels, the discount rates, and objective functions which complete the matrix for subsequent lp analysis and solution.

¹ See Range RAM Users' Manual Part II: Using Range RAM.

B—Calculation of

Output Coefficients

The required inputs and generated outputs corresponding to the per unit area per interval costs and benefits of the state transformations are known as the input and output coefficients. These coefficients must be defined and determined by the Range RAM user. However, in order to improve the precision and speed with which the calculations of output coefficients can be performed, the RANGE/MTX program contains certain options which free the user from these tasks. The coefficients for three types of output can be calculated with the computer: harvested forage, animal months of grazing, and rental fee income.

The precise definition of these outputs must be left to the planner, but their general interpretation should be as follows: harvested forage—the actual amount of vegetable matter harvested (or planned to be harvested) by grazing animals; animal months (AM's) of grazing—the number of animal months of grazing provided by the amount of harvested forage; rental fee income—the revenue derived from leasing out range land for grazing use.

For each resource class for which the planner decides to rely on computer calculations of the harvested forage coefficients, he must specify levels for three characteristics: (a) forage production² (in lbs or 1000's lbs) per unit area, (b) allowable use (in percent) per unit area, and (c) grazing intensity (in percent) per unit area. The levels for all three characteristics must represent the average per unit area values of the resource class as a whole. Instead of specifying the levels of forage production, the planner may substitute the levels of herbage production and herbage availability-palatability. Whereas the level of grazing intensity is a decision of range use, levels of the other characteristics are functions of the variable state of the resource class. They can, therefore, be used as state parameters and their specific levels can thus serve to describe the states of a resource class.

When RANGE/MTX is used to calculate the coefficients of harvested forage, then forage production/unit area, or herbage production/unit area and herbage availability-palatability must be specified as state parameters. Allowable use can also be specified as a state parameter, but may, like grazing intensity, be specified separately on the prescribed RANGE/MTX data input forms. The third state parameter may

never be used for the calculation of output coefficients, and is reserved for qualitative range resource characteristics. For example, degree of soil surface erosion might be used as a qualitative indicator of the "health" of a resource class.

Equation 1 describes the relationship between forage production, herbage production, and herbage availability-palatability. Equation 2 describes the relationship between harvested forage, forage production, allowable use, and grazing intensity.

$$(1) \quad FP = (HP) (HAP)$$

$$(2) \quad HF = (FP) (AU) (GI)$$

in which FP is the forage production per unit area (in pounds or 1000's pounds); HP is the herbage production per unit area (in pounds or 1000's pounds); HAP is the herbage availability-palatability (in percent); HF is the amount of harvested forage per unit area (in pounds or 1000's pounds); AU is the allowable use factor of the herbage or forage; and GI is the grazing intensity.

To obtain the per interval values of HF (i.e. HF_I or the HF coefficient), time related functions must be known for FP (or HP and HAP), AU, and GI. An estimate of the true value of HF_I is obtained with RANGE/MTX by using equation 3 or 4.

$$(3) \quad (\widehat{HF})_I = \sum_{i=1}^I \{ (HP)_i (HAP)_i \} (AU)_I (GI)_I$$

$$(4) \quad (\widehat{HF})_I = \sum_{i=1}^I \{ (FP)_i (AU)_i \} (GI)_I$$

in which $(\widehat{HF})_I$ is the estimated value of $(HF)_I$; I is the number of years in the planning interval; and $(HP)_i$, $(HAP)_i$, $(FP)_i$, and $(AU)_i$, are the average annual values for herbage production, herbage availability-palatability, forage production, and allowable use. $(AU)_I$ and $(GI)_I$ represent the average allowable use and grazing intensity over interval I.

When HP and HAP, or FP and AU are used as the state parameters, their respective annual values for the first and last year in the planning interval must always be specified by the planner. Furthermore, the planner must specify a "parameter pattern" or "practice implementation pattern"³ for both the structural and non-structural management practices. In all, the planner has a choice from sixteen alternative patterns from which he can make his selection. The RANGE/

² Forage production as used here must represent the production of palatable and available herbage. It is similar to the definition given in the Forest Service Manual 2212.71a, Amendment No. 4, July 1968.

³ See Range RAM Users' Manual Part I: Users' Guide and Instructions.

MTX program then determines the annual—within the interval—values of the state parameters on the basis of these specified patterns and the first and last year values of the state parameters.

Once the coefficients of harvested forage have been determined, the coefficients for other related output commodities can be derived. For this reason, output conversion factors are used. An output conversion factor constitutes a ratio (expressed as a decimal fraction) that relates the harvested forage coefficients ($\widehat{HF}_I$) to other output commodities. Equation 5 describes this relationship formally.

$$5) \quad (\widehat{HF})_I \times (cf)_j = C_j$$

in which C_j represents the output coefficient of commodity j ; $(\widehat{HF})_I$ represents the estimate of the harvested forage coefficient; $(cf)_j$ represents the output conversion factor for commodity j ; and $j = 1, 2, \dots$, where $n = 9$. The conversion factor $(cf)_j$ for a given commodity j may vary for different resource classes. Variability in $(cf)_j$ allows, for example, for the con-

sideration of differences in forage quality, harvested in different resource classes.

Some examples may help explain the use of the conversion factor. Consider a resource class which is grazed by livestock only. Harvested forage is measured in thousands of pounds, and 0.8 thousand pounds of harvested forage supports one animal month (AM) of grazing. Then a value of 1.25 for the conversion factor translates harvested forage into AM's, i.e. $\widehat{HF}_I \times 1.25 = \text{AM}$ of livestock grazing. If one AM of livestock grazing has a rental fee value of \$1.50, then a value of 1.875 for a second conversion factor translates harvested forage into dollar revenue, i.e. $\widehat{HF}_I \times 1.875 = \text{dollar revenue}$. If the resource class were grazed by both livestock and game, and only 75 percent of the harvested forage goes towards livestock consumption, then conversion factors of .75 and .25 will give the forage harvested by livestock and game respectively. If the livestock again requires 0.8 thousand pounds of forage for each animal month of grazing, then the conversion factor C_j which translates $\widehat{HF}_I$ into AM's of livestock grazing must be equal to .9375 (i.e., $.75 \times 1.25$).

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The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Jansen, Henricus C.

1976. **Range RAM ... a long-term planning method for managing grazing lands.** USDA Forest Serv. Res. Paper PSW-120, 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

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CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Methods	4
Reservation Systems	4
Questionnaire Sampling	4
Data Analysis	5
Characteristics of the Campers Sampled	5
Camper Appraisal of Reservation Systems	7
Reservation Sales Systems	7
Public Information Sources	8
Advance Planning Requirements	8
Preferences of Campers on Choices Offered	9
Reservation vs. First-Come-First Served	9
Campground vs. Campsite	11
Proportion of Campgrounds to be Reserved	12
Enjoyment of Camping Experience	13
Literature Cited	15

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SUMMARY

Magill, Arthur W.

1976. **Campsite reservation systems . . . the camper's viewpoint.**

USDA Forest Serv. Res. Paper PSW-121, 15 p. Pacific Southwest
Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 907.2

Retrieval Terms: recreation; camp sites; reservation systems; user attitudes; user characteristics.

Two pilot campsite reservation systems were tested by Federal resource agencies during the summer of 1973: The Ticketron system by the Forest Service in the San Bernardino and Inyo National Forests, and the American Express system by the Park Service in Yosemite and five other National Parks.¹ In order to determine public response to these systems, I mailed more than 2000 questionnaires to survey the attitudes and characteristics of campers who had come into contact with the reservation systems during the latter half of that summer.

This study provides the only information available on camper reaction to campsite reservation systems by both agencies, and should prove essential to the design and implementation of future reservation systems. The limitations of the data must be recognized, however: although the sample response was good (1211 questionnaires), it was divided unequally among different types of campers; the sampling period was short (August 13 to September 9); and the sites studied offered very little opportunity to sample opinions of certain segments of the recreation population (boaters, hunters, water-skiers, and users of off-road vehicles).

Respondents are referred to collectively as "campers" (1211); they are divided between Users (855) who camped in a reservation campground, Cancelers (136) who canceled or disregarded their reservations, Potential Users (200) who camped at nearby nonreservation campgrounds, and Turnaways (20) who were unable to get a campsite in a reservation campground.

The responses on the various items covered in the questionnaires were tabulated and analyzed from several points of view, and results (summarized below) are presented in the order considered most useful, rather than in order of importance. Resource

managers will place varying emphasis on the items discussed, according to the varying problems of the areas they manage. Outstanding, however, are findings pointing to the need for one reservation company to serve all agencies (thereby improving public services and reducing confusion) and to the need for more audience-directed information programs on the reservation system.

1. Campers were generally well-educated professionals or managers who were earning high incomes. Most campers were experienced: 44 percent had been camping over 10 years and 62 percent over 5 years.

2. About 75 percent of campers preferred *one* campsite reservation company to sell reservations for all Federally owned campgrounds. Campers could then make reservations at one time and place regardless of the agency operating the campground, and they could be referred to alternate campgrounds if their first choice was not available.

3. The limited public information programs were not as successful as desired. Only 30 percent of respondents were influenced by radio, television, newspapers, or magazines, and newspapers accounted for over half of this group. By contrast, 41 percent of campers had learned about campsite reservations from friends and 21 percent only when they went camping. Results suggest that managers should identify and use the media most likely to reach campers.

4. Seventy-seven percent of all campers had jobs that allowed them to plan trips more than 3 weeks in advance, and 34 percent could plan more than 12 weeks. Seventy-three percent of Users and 82 percent of Cancelers preferred advance planning. In practice, however, 60 percent of all campers usually planned their trips less than 5 weeks in advance.

5. Eighty-one percent of Users and 76 percent of all campers preferred to make advance reservations to get a campsite. In practice, about 75 percent of Users got sites by making reservations, whereas the remaining 25 percent were successful "drop-ins." Forty-seven percent of Cancelers, against only 17 percent of

¹Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

Users, had made their reservations by telephone. Thus, increases in telephone services may lead to increases in cancellations or no-shows as a consequence of greater ease in making reservations.

6. The first-come-first-served method of campsite selection was preferred by 39 percent of weekday Forest Service Users and 43 percent of Forest Service Users with recreational vehicles. Forty-four percent of weekday Forest Service Users were successful in obtaining a campsite this way. More retirees, sales persons, and blue collar workers in the Forest Service Users group than in the National Park Users group preferred first-come-first-served campsite selection.

7. Seventy-four percent of Users wanted their first choice of campground and would accept more restricted choice of campsite. Eighty-four percent got their first choice of campground but only 40 percent got their choice of campsite. Of the 181 Users who thought first choice of campsite most important and who did not get their first choice, 52 percent were disappointed with their camping trip. But 61 percent had a good trip despite not getting their choice of

campground or campsite. A small number of write-in responses revealed that campers liked being assured a place to camp, and preferred to pick their own campsite, especially in preference to preassignment by computer.

8. Reservation systems should be used at all campgrounds or at not less than three-quarters of them according to 51 percent of Users and 60 percent of Cancelers.

9. Ninety-four percent of the Users stated they enjoyed their vacation. Some Users of Forest Service campgrounds registered disappointment, possibly because they could not pick their campsite. Sixty-one percent of those Users who had stayed at the same campground both before and after reservations were instituted had a more enjoyable experience with reservations. Eighty-seven percent of Users and most Cancelers were willing to make reservations for future camping trips. Campground characteristics also influenced campers' enjoyment and willingness to accept reservation requirements in the future.

Visitation at campgrounds, winter sports centers, wilderness areas, and other outdoor recreation sites has been increasing during the past decade. As a result, many sites are becoming overcrowded, subject to severe deterioration, and less likely to provide quality recreational experiences. Resource managers are looking for ways to disperse use and even limit use of areas under stress. Reservation systems, referral systems, user fees, and outright user limits are the most common approaches either proposed or in use. Currently, reservation systems are being closely examined for guides to design of future systems.

Although reservation systems offer advantages in greater site protection and reduction of crowding, there are also some disadvantages. Historically, the Forest Service and the National Park Service have told the public that the Forests and Parks are "theirs." Slogans and statements such as these have been used: "Protect and Enjoy Your National Forest Heritage," "The National Forests . . . America's Playground," or "As citizens of the United States, you are Heritage," "The National Forests . . . America's Playground," or "As citizens of the United States, you are a part owner of the Yosemite Valley . . ." Some visitors may doubt the "public" nature of the Forests and Parks when faced with reservation requirements, user fees, and access through commercial reservation companies. In addition, any regimentation and mechanization may prove objectionable to some users; who see them as characteristic of the urban life they are trying to escape. Reservation systems may be very restrictive—even oppressive to people who like to roam, free of time schedules. Reservation systems may place other groups at a competitive disadvantage—those who are unable to schedule their vacations well in advance, and those who live in communities not served by a reservation office.

During the summer of 1973, the Forest Service and the National Park Service tested two different campsite reservation systems in two National Forests and six National Parks. The Forest Service contracted with Ticketron, Incorporated, a company experienced in sports and entertainment reservations and in campsite reservations for the California State Park System, to sell reservations for selected campgrounds

in the Inyo and San Bernardino National Forests. The Park Service contracted with the American Express Company, experienced in hotel and motel reservations, to serve Yosemite and five other National Parks across the country. This paper reports the results of a survey I made by questionnaire to determine campers' response to these reservations systems in California that summer. Data developed by the survey should be useful to the Forest Service and National Park Service in identifying the need for a coordinated reservation system, improving the effectiveness of public information programs, and possibly reducing the number of "no-shows" and cancellations. By assessing preferences for reservations vs. "first-come-first-served" systems, and identifying difficulties users encounter trying to make reservations, the survey may help managers to eliminate sources of discrimination.

The future of campground reservation systems is not easy to predict. American Express ceased to operate its campground reservation system when its contract with the Park Service ended—fortunately after completion of this survey. In 1974, the Park Service contracted with another company, but operational difficulties led to termination of the contract. In 1975, the Service had not contracted with any reservation company, although a few parks were operating noncomputerized reservation systems. In late summer of 1973, Congress enacted Public Law 93-81, which eliminated camping fees for most Federal campgrounds. An increase in no-shows occurred because only the reservation fee was forfeited if the reservation was not used. Consequently, the Forest Service did not renew its contract with Ticketron during the 1974 season. The law was amended by Public Law 93-303 in 1974, but this action came too late for the Forest Service to start its system that year. Ticketron again operated a reservation system for the Service in 1975. Though still a pilot program restricted to 25 campgrounds, it extended to six National Forests. In the further steps that are yet to be taken, in system development, the information gained in this study should be useful to system planners.

METHODS

Reservation Systems

Both Ticketron and American Express reservations were available directly from ticket offices or by mail from company reservation centers upon payment of the campground fee plus a \$1.50 reservation fee. Offices were linked to a computer center which kept track of reservations and available space so the operator at the ticket office could quickly determine availability and register reservations. American Express took orders by phone as well, but charged \$3.00 for such reservations. Payment had to be received before phone or mail orders were final. For cancellations before the reservation period had started, both companies would refund the campground fee but deduct the reservation fee as well as a \$1.50 cancellation fee.

Though similar, the Ticketron and American Express systems differed in ways that affected the results of this survey. The differences were in the advance reservation procedures and in the deadline imposed. Both companies could have made reservations for more than 90 days in advance, but the Forest Service imposed a 30-day limit on its reservations and the Park Service imposed a 90-day limit. Another limitation in practice was that Ticketron did not accept reservations by mail until late in the season, and even then it received very few.

From the campers' point of view, the major difference in the two systems was the deadline for making reservations. Ticketron orders for any Friday-through-Thursday period had to be placed by the previous Monday. This meant, for example, that a campsite for a trip scheduled to begin on Friday, the 12th, had to be reserved by Monday, the 8th. But if the trip were to begin on Thursday, the 11th, the order had to be placed by Monday, the 1st. This allowed time for the reservations to be mailed to each campground by Thursday and allowed campground personnel to know exactly how much space remained for campers who might drop in without reservations during the following week.

American Express took orders for any day up to midnight of the previous day, sending them electronically to the park headquarters as they were made. This was, of course, more convenient for the camper planning a last-minute trip, but it was a nightmare for campground personnel, who did not know until early morning what the final disposition of their campsites would be for that day. It also meant that the drop-in camper, who had no reservation and could not make

one from the campground itself, would not know from one day to the next how long he could keep his campsite.

Questionnaire Sampling

The questionnaire was designed to elicit a wide variety of information, including campers' opinions about the reservation systems, details of their use of the systems, and characteristics of the campers themselves. Four distinct groups of campers were identified for the purposes of this study:

Users—Persons who obtained a campsite at a reservation campground either through the reservation system or as "drop-ins" getting an unreserved campsite.

Turnaways—Persons who could not gain entrance to a campground because they had no reservation.

Cancelers and No-Shows—Persons who canceled their reservations and persons who neither canceled nor used their reservations.

Potential Users—Persons who did not use reservation campgrounds, but who camped in nearby campgrounds.

Because some questions did not apply to all groups, and because responses often differed notably according to group, the results are generally tabulated here for each group separately. "Cancelers" stands for both no-shows and cancelers in the text, and "Users" are identified as Forest Service (FS) or National Park-Yosemite only—(NP) wherever that distinction is important. "Campers" includes all respondents to questionnaires except Turnaways.

Questionnaires were mailed to the registered individual or licensee of more than 2000 camper units. Names had been obtained from American Express terminal print-outs, Ticketron applicant records, cancellation records, or automobile license numbers collected by campground attendants. Two reminders at 3-week intervals produced an eventual 72 percent response, but many of these responses were unusable because their control numbers had been removed or they were for trips taken outside the study period. Fifty-nine percent, or 1211 questionnaires, were usable.

Midway through the summer, Congress passed Public Law 93-81 eliminating camping fees from August 1 through the end of the camping season on most Federal campgrounds including those used for this study. This distorted the reservation picture, because many campers then made a number of reservations, only intending to use one or two. Then, a failure of communications with some company personnel meant that names of National Forest Users were not collected until August 13. To obtain comparable samples from both systems, therefore, I constricted the sampling period from August 13 to September 9. The resulting sample was smaller than that hoped for, but still usable. An additional sample was taken from Yosemite for a 15-day period before August 1 to assess the impact of the camping fee removal.

The sample of Turnaways was smaller than anticipated, perhaps because the shortage of gasoline had decreased the demand for campsites. Although the sample was small and therefore unreliable, the response was similar in pattern to those established for other types of respondents. Decreased demand also necessitated a 100 percent sample of Forest Service campgrounds, whereas at Yosemite, where demand remained high, a random sample of 22 campers per day was taken. Because Ticketron did not keep the names of Cancelers, that category is represented solely by a random sample of seven per day from Yosemite. The Park Service had the only record of Potential Users. They were randomly sampled from

unreserved campgrounds near Yosemite at the rate of five per day. The numbers of respondents for each category were: NP Users—463, FS Users—392, Cancelers—136, Potential Users—200, Turnaways—20.

Data Analysis

Replies to the questionnaires were analyzed from several points of view. The "Statistical Package for the Social Sciences," (Nie and others 1970) was the computer program used to obtain the cross tabulations for the study. The responses to the questionnaire items were analyzed by categories of users, camping location, and day of the week. In addition, cross tabulations were used to relate the influences of preferences, experiences, or visitor characteristics.

Nonrespondees were not sampled to determine if their failure to respond introduced bias. I examined nonresponse by looking for differences between response waves. The assumption is that if there were no differences between respondents of the first wave and the respondents of follow-up mailings, who were nonrespondents to the first mailing, then there would be no difference between respondents and nonrespondents; that is, second and third wave respondents may be expected to behave like nonrespondents. The wave analysis showed no apparent differences.

Comparison of preferences of Yosemite Users before and after removal of camping fees did not reveal any differences.

CHARACTERISTICS OF THE CAMPERS SAMPLED

The information gathered from the questionnaires gave a general view of camper characteristics. Place of residence; age, occupation, income, and education were recorded for each respondent. No information on other members of each camping party was requested.

A preponderance of Users (95 percent) were Californians—not surprising for campgrounds within a State whose neighbors have low populations and considerable opportunities for wildland recreation. (In contrast, a survey of Indiana campers [Taylor and Knudson 1972] found that out-of-state visitors were 35 percent of the campers, probably because nearby States were densely populated.) Even more lopsided in proportion of Californians were the data from the San Bernardino National Forest, where only one

camper out of 386 surveyed was from out of State, as compared to 41 out of 456 National Park campers (*table 1*). Because most National Forest Users surveyed had camped on the San Bernardino, the distribution of residence within the State was predictable: the great majority (80 percent) were from southern California, only two were from the Bay Area, and the remainder were from widely scattered localities. Yosemite, on the other hand, remote but widely known, drew more equally from both population centers—46 percent from southern California and 32 percent from the Bay Area.

Most respondents were between 25 and 44 years old. Few age differences were found between categories of campers, except that more people under 25 were National Park Users and more people 45 and

Table 1—Residence of campground Users sampled, camping at National Park (NP) or National Forest (FS)

Residence	NP Users	FS Users	All Users
	Percent		
By State:	(n=456)	(n=386)	(n=842)
California	91.0	99.7	95.0
Other States	9.0	0.3	5.0
Within California:	(n=409)	(n=379)	(n=788)
Rural areas and towns less than 10,000	12.2	15.8	14.0
Cities of 10,000 to 50,000	4.9	2.9	3.9
Urban areas (over 50,000)			
Great Valley cities—Sacramento, Fresno, Bakersfield, etc.	5.1	0.5	2.9
Los Angeles and Southern California	45.5	80.2	62.2
San Francisco Bay area	32.3	0.5	17.0

over were National Forest Users, and that more people in the Potential Users group were under 25 than in the other categories.

The occupation, education, and income data for respondents revealed important differences from the general population. Sixty-two percent of all Users had white-collar occupations: 46 percent as professionals, educators, or technicians; another 15 percent as managers and proprietors. Education and income were in line with occupation: 71 percent of all Users had attended college and 83 percent reported incomes over \$10,000. These levels are obviously well above those recorded in 1972 for Californians generally, and they are even above those reported for Pacific Northwest wilderness users in 1968 (table 2).

The levels of occupation, income, and education of NP Users were notably higher than those of FS Users. Of NP Users, 79 percent had attended college; 36 percent had done graduate work; 53 percent were professionals, educators, or technicians; and 19 percent made more than \$25,000 a year, whereas the corresponding figures for FS Users were only 62 percent (college); 21 percent (graduate work); 39 percent (professionals); and 10 percent (high incomes).

Most of those surveyed had considerable experience camping. Forty-five percent of Users had been camping for more than 10 years, and 61 percent had been camping for more than 5 years, whereas 52 percent had camped at the same campground in

previous years. Potential Users were slightly more experienced (71 percent over 5 years) and Cancelers were slightly less experienced (53 percent over 5 years).

In general, FS Users, Turnaways, and Potential Users took frequent trips of short duration and NP Users and Cancelers took fewer trips of long duration. Similarly, most NP Users made reservations only once, while most FS Users made reservations more than once and a considerable number did so from four to six times:

Table 2—Education and income levels of campground Users sampled, compared with levels reported for other groups (NP, National Park; FS, National Forest)

Item	NP Users	FS Users	Wilderness Users ¹	California	U.S.
	Percent				
Education:					
College, 4 yr or more				² 13.4	² 11.0
College, 4 yr or less	43.0	40.9	35.6		
College, more than 4 yr	36.2	20.8	28.2		
Income:					
Less than \$10,000	15.2	18.7	—	³ 45.3	³ 52.8
\$10,000-25,000	66.1	71.5	—	48.6	42.6
More than \$25,000	18.8	9.9	—	6.1	4.6

¹Hendee and others 1968; data for 1965.

²U.S. Dep. Commerce 1972; data for 1970.

³U.S. Dep. Commerce 1972; data for 1969.

	NP Users	FS Users	All Users
	Percent		
Times reserved:	(n=458)	(n=303)	(n=761)
1	61.8	40.9	53.5
2 to 3	32.3	38.6	34.8
4 to 6	5.5	16.8	10.0
7 to 12	0.4	3.3	1.6
More than 13	0	0.3	0.1

It seems probable that a major reason for this tendency was the distance that NP Users had to travel from major population centers to Yosemite, usually 200 miles or more; most FS Users traveled less than 100 miles.

Nearly two-thirds of all Users camped in groups of three to seven people; there were very few parties of

more than eighteen or less than two people. There was a slight tendency toward large groups among FS Users. Single families comprised 57 percent of Users generally and 64 percent of NP Users. Again, FS Users tended slightly toward multiple-family groups: 42 percent as compared to 24 percent of NP Users.

Campers varied widely in their use of camping equipment. Nearly two-thirds of the FS Users used some kind of recreational vehicle as compared to less than half of the NP Users, and most of the remainder of each type of Users used tents:

	<i>NP Users</i>	<i>FS Users</i>	<i>Total Users</i>
	<i>Percent</i>		
Equipment:	(n=456)	(n=382)	(n=838)
No equipment	3.7	3.7	3.7
Tent	50.2	33.8	42.7
Tent trailer	9.6	10.2	9.9
Camper	16.9	24.1	20.2
Trailer	11.0	21.7	15.9
Motor home	6.6	5.5	6.1
Other	2.0	1.0	1.6

CAMPER APPRAISAL OF RESERVATION SYSTEM

Responses to questionnaire items on the reservation system and the manner in which campers use it suggested several areas where improvement is needed. These include a systematic procedure for referring campers to vacant campsites, and a more effective information program, with dispersal of information through user-specific media. The questionnaire responses also indicated that although most campers can plan vacations far enough in advance to allow time to use a reservation system, they generally tend to wait until the last few weeks before planning trips.

Reservation Sales Systems

A principal problem of the campsite reservation systems was the impossibility of making reservations at one time and place for campgrounds run by different State and Federal agencies. There was no systematic procedure for referring a potential camper from the fully-reserved campground of one agency to the nearby unreserved campground of another. The public lacked knowledge of alternative campgrounds and was confused about which agencies administered them and which companies sold reservations. The problem was reflected in the desire of many of those surveyed to have one reservation company selling reservations to all campgrounds, regardless of the administrative agency: 30 percent wanted a single company for all Federal campgrounds and another 44 percent wanted reservations to be sold by the company that handles State Park reservations (*table 3*). These two responses are interpreted to mean that 74 percent of the respondents wanted reservations to be sold by one reservation company, especially since only 15 percent stated that they wanted different companies to sell for different agencies.

Table 3—Camper opinions about who should sell campsite reservations

Choices	Users	Cancelers	Potential Users	All campers
	<i>Percent</i>			
	(n=768)	(n=120)	(n=181)	(n=1069)
One company for all Federal agencies	27.2	31.7	39.8	29.8
Different companies for different agencies	15.5	16.7	11.6	15.0
Same company that sells for the State	47.7	43.3	30.4	44.2
Other	9.6	8.3	18.2	10.9

However convenient it may be to have one company represent all agencies, it may well be legally impracticable. Because Government contracts are made by bid, more than one reservation company might bid successfully for the separate contracts of the different State and Federal agencies. Nevertheless, some measures need to be taken to insure greater coordination between all agencies and all companies concerned with reservation camping. Perhaps one company could make reservations for another through its own computer terminal—the way most airlines do now. At a minimum, there needs to be some sort of referral service between companies and between agencies.

Differences between respondent groups suggest that Potential Users may have been less familiar with the State's system than campers who had made reservations. The "other" response may indicate a preference for not making reservations—getting campsites

on a first-come-first-served basis, as discussed in a later section.

Public Information Sources

Both the Forest Service and the Park Service conducted public information campaigns in advance of their pilot reservation programs to acquaint the public with the need for reservations and the procedures for obtaining them. But because the pilot programs were restricted in scope and duration, the information campaigns were also limited.

Even allowing for this limitation, effects were disappointing. Only about a third of all campers had learned of the reservation requirement from the mass media, rather than from friends or from actual camping without reservation (*table 4*). For more than half of this group, the "mass media" was the newspapers. The figures show that more NP Users than FS Users had learned about reservations from the media. Furthermore, more FS Users did not know about the system until they went camping, but about half of the NP Users had learned about reservations from their friends.

These results essentially agree with similar studies. Fazio and Gilbert (1974) found that an intensive information program about wilderness permits reached half a million persons in Colorado, but very few of these were wilderness users. Taylor and Knudson (1972) found that 63 percent of the campers in Indiana State campgrounds relied on friends for information rather than on the State's free and easily obtainable brochures. The Park Service survey (1974) showed 40 percent reliance on friends.

When asked which company was nearest their homes, 57 percent of all Users named Ticketron and less than half this many (26 percent) named American Express (*table 4*). Possible explanations are that Ticketron is familiar to users of the California State Park System and its offices are located in major department stores. American Express sold reservations in its own offices or in Ramada Inns, both of which are more likely to do business with the traveler than with the local resident. Sixty-three percent of the Users and progressively smaller percentages of the Cancelers and Potential Users indicated that offices were located within 10 miles of their homes. As might be expected, both questions revealed considerable ignorance about office locations among those who had not used the systems.

These discouraging results indicate that more extensive information programs and more selective targeting are needed to assure that prospective campers have the best possible opportunity to be well-informed about the existence of a reservation system, the operation of reservation systems and the availability of vacant campsites.

Advance Planning Requirements

It seemed likely that a reservation system might pose a hardship for campers whose jobs allow vacation planning only 2 or 3 weeks in advance. Short lead times might not allow campers to make reservations at the locations of their choice, especially during periods of peak use. Fortunately, many people can plan vacations in advance: more than three-quarters of all campers can plan more than 2 weeks; a

Table 4—Campers' source of information on the reservation systems, and knowledge of reservation office nearest home, by camper group (NP, National Park; FS, National Forest)

Item	NP Users	FS Users	All Users	Cancelers	Potential Users	All campers
	Percent					
Information source:	(n=444)	(n=386)	(n=830)	(n=131)	(n=175)	(n=1136)
Newspapers	18.5	17.6	18.1	19.8	19.4	18.5
Television	3.6	1.8	2.8	5.3	4.6	3.3
Radio	2.5	1.3	1.9	1.5	5.7	2.5
Magazine	8.3	2.6	5.7	9.9	4.0	5.9
Friend	49.5	36.0	43.3	43.5	30.3	41.3
Reservation company	10.0	4.7	7.6	12.2	4.0	7.6
Went camping	7.4	36.0	20.7	7.6	32.0	21.0
Office nearest home:	(n=453)	(n=388)	(n=841)	(n=135)	(n=198)	(n=1174)
American Express	47.5	0.8	25.9	43.7	8.1	25.0
Ticketron	32.2	86.1	57.1	35.6	41.4	52.0
Don't Know	20.3	13.1	17.1	20.7	50.5	23.1

Table 5—Planning patterns of different groups of campers as indicated by job conditions and by preference

Item	Users	Cancelers	Potential Users	All campers
	Percent			
Planning time available:	(n=778)	(n=126)	(n=184)	(n=1088)
1 to 2 weeks	14.3	7.9	15.8	13.8
3 to 5 weeks	18.4	15.1	16.3	17.6
6 to 8 weeks	12.1	15.1	12.0	12.4
9 to 12 weeks	13.9	13.5	9.2	13.1
More than 12 weeks	33.0	42.1	31.0	33.7
Unemployed or response not clear	8.4	6.4	15.7	9.4
Preference:	(n=786)	(n=126)	(n=191)	(n=1103)
Plan ahead	73.4	82.5	36.1	68.0
Find campsites as needed	26.6	17.5	63.9	32.0

third can plan more than 12 weeks (table 5). Not only did jobs allow people to plan their vacations in advance, but most Users and Cancelers preferred advance planning. Unfortunately, most Potential Users

and Turnaways preferred getting their campsites as they travel, but that could be expected—these groups are most strongly in favor of the first-come-first-served pattern.

Despite their freedom to plan in advance and their professed willingness to do so, a majority of all campers, representing majorities of both Users who like to plan and those who do not, said that they usually planned their trips 5 weeks or less in advance (table 6). Forty-one percent of the FS Users planned only 1 to 2 weeks ahead, and although there is a weak tendency for some NP Users and Cancelers to plan ahead by 9 weeks or more, the majority are usually short-term planners. Thus, most campers could easily use a reservation system because they have the freedom to plan in advance. However, as competition for campsites increases, the proportion who can get reservations will shrink toward the one-third that have jobs that allow advanced planning of more than 12 weeks.

The 4- to 10-day advance planning requirement imposed by Ticketron thus might not present any real problem for the camper. Also, as the public accepts the reservation method, many campgrounds will be filled far ahead of the deadline.

Table 6—Length of time campers usually plan trips in advance

Plan-ahead time usually taken	NP Users	FS Users	All Users	Cancelers	Potential Users	All Campers
	Percent					
	(n=447)	(n=352)	(n=799)	(n=127)	(n=185)	(n=1111)
1 to 2 weeks	21.5	41.2	30.2	26.8	29.7	29.7
3 to 5 weeks	32.9	28.1	30.8	27.6	31.9	30.6
6 to 8 weeks	17.9	15.9	17.0	21.3	15.7	17.3
9 to 12 weeks	11.9	5.7	9.1	14.2	3.8	8.8
Over 12 weeks	13.2	6.0	10.0	7.0	10.3	9.8
Response not clear	2.7	3.1	2.9	1.6	7.6	3.5

PREFERENCES OF CAMPERS ON CHOICES OFFERED

Responses to questionnaire items on campers' basic choices revealed that generally, campers wanted to be able to make reservations, but that a minority had a definite preference for a first-come-first-served plan. Also, most users were more concerned with choice of campground than choice of campsite. Finally, a majority of campers wanted most campgrounds placed on reservation, whereas the advocates

of the first-come-first-served plan did not want any campgrounds reserved.

Reservation vs. First Come—First Served

Answers to several different questions indicated broad public acceptance of the reservation idea.

Campers were asked how they preferred to obtain campsites, and were offered the traditional first-come-first-served method at the campground, among the choices. Four-fifths of all Users and three-quarters of all campers preferred to make reservations—most by going in person to a ticket office, nearly as many by telephoning, and a few by writing (*table 7*). These preferences for reservations, and for phone reservations in particular, were markedly higher among NP Users and Cancelers and lower among Potential Users and FS Users (particularly mid-week FS Users). Overall, these statistics bear out the Park Service study (1974) which showed 86 percent of its Yosemite respondents in favor of reservations.

Replies to other questions indicated that campers generally acted upon their preferences within the limitations of the existing reservation systems. Three-quarters of all Users made reservations (*table 7*). Just less than two-thirds of all reservations were made in person—but it should be remembered that National Forest reservations could not be made by phone and could be made by mail only late in the season. Nearly

half of the Cancelers had used the phone, in keeping with their heavy preference for phones. Possibly the Cancelers who prefer to make reservations by phone are not as fully committed to taking a trip as the Users who make the effort to go to a ticket office. If so, increased phone service may lead to increased cancellations and unused reservations. On the other hand, it is better to have campers cancel, and thereby free campsites for use by drop-in campers, than to have them hold their reservations and leave the sites unused.

Users who preferred first-come-first-served campsite selection were in the minority, but knowledge of some of the characteristics of such campers may prove useful to resource managers. More FS Users, than NP Users (especially weekday campers) preferred this method (*table 7*). Furthermore, 44 percent of the weekday FS Users did obtain campsites without making reservations. On the question of preference for planning campsite locations in advance against finding one each day, FS and NP Users demonstrated occupational differences. Thus, re-

Table 7—Campers' preference for obtaining campsites, and their usual practice in reserving campsites

Camper category	Number of respondents		First-come-first-served		Ticket office reservation		Telephone reservation		Mail reservation		Other (Preference) ¹
	Preference	Practice	Preference	Practice	Preference	Practice	Preference	Practice	Preference	Practice	
	Percent										
National Park Users											
Weekday	309	313	10.7	16.9	36.2	43.8	40.5	30.0	11.0	9.3	1.6
Weekend	140	142	7.1	18.3	38.6	49.3	41.4	21.8	11.4	10.6	1.4
All NP	449	455	9.6	17.4	37.0	45.5	40.8	27.5	11.1	9.7	1.5
Forest Service Users											
Weekday	158	151	38.6	43.7	37.3	47.0	18.4	4.0	3.8	5.3	1.9
Weekend	219	218	19.6	28.4	58.0	63.8	20.5	5.5	1.8	2.3	0.0
All FS	377	369	27.6	34.7	49.3	56.9	19.6	4.9	2.7	3.5	0.8
All Users	826	824	17.8	25.1	42.6	50.6	31.1	17.4	7.3	6.9	1.2
Cancelers	131	134	13.0	20.1	21.4	25.4	58.8	47.0	4.6	7.5	2.3
Potential Users	195	—	49.7	—	13.3	—	26.7	—	7.7	—	2.6
Users and Cancelers	—	958	—	24.4	—	47.1	—	21.5	—	7.0	—
All campers	1152	—	22.7	—	35.2	—	33.5	—	7.0	—	1.6

¹No "other" methods were actually available.

Table 8—Preference of Users for alternate methods of obtaining campsites, according to occupation

User group and alternative	Preference by occupation (partial listing)				
	Retired persons	Sales persons	Craftsmen	Operatives	Laborers
	<i>Percent</i>				
National Park Users:	(n=21)	(n=17)	(n=46)	(n= 9)	(n=18)
Plan in advance	86	82	73	89	89
Find camp enroute	14	18	28	11	11
National Forest Users:	(n=24)	(n=28)	(n=57)	(n=19)	(n=16)
Plan in advance	33	64	54	53	62
Find camp enroute	68	36	46	47	38

tirees, salespeople, and blue-collar workers who preferred “first-served” selections were more likely to be Forest Service Users (*table 8*). Users whose jobs allowed them to plan only two weeks or less in advance of going on their vacation were not numerous, but 42 percent of such users ($n = 123$) preferred the “first-served” method, compared to 21 percent ($n = 561$) who could plan ahead more than two weeks. Among FS Users, 43 percent of those ($n = 185$) with sophisticated recreational vehicles (camper, trailer, or motor home) preferred getting campsites on a “first-served” basis, in contrast to only 26 percent of those ($n = 295$) without such equipment. As might have been expected, half of the Potential Users and over three-fifths of the Turnaways preferred the “first-served” campsite selection method, whereas only 18 and 13 percent of the Users and Cancelers preferred this method. Obviously, a segment of the camping public prefers to be independent in obtaining campsites rather than to seek the assurance associated with computerized campsite reservations.

Campground vs. Campsite

Seventy-four percent of all Users said that getting their first choice of a campground was much more important than getting a particular campsite within a campground. More FS than NP Users did prefer to choose the campsite, however—30 percent against 22 percent. Thirty-nine percent of the FS Users who were “nonplanners” (their jobs did not allow planning more than 5 weeks in advance) preferred to choose the campsite against only 20 percent of the “planners” (their jobs allowed planning of 6 weeks or more).

Eighty-four percent of the Users actually got their choice of campground, whereas only 40 percent got a preferred campsite. The proportion of failure was 67 percent for FS Users against 55 percent for NP Users.

Users varied in their reactions to failure to get their first choice of either campground or campsite. For example, 68 percent of the Users who preferred a choice of campground were not disappointed with their trip just because they did not get their choice. Only a very small percentage of the Users were disappointed with their trip and did not enjoy their stay at the campground as a consequence of not getting their first choice; over 30 percent were disappointed with their trip but still enjoyed their stay; and about twice as many had a good trip and enjoyed their stay.

More of those Users who ranked choice of campsite as most important expressed disappointment than did those who preferred choice of campground; this is understandable because more “campsite” Users than “campground” Users failed to get their choices. However, only 9 percent of the “campground” group and 24 percent of the “campsite” group directly related their disappointment to this cause.

The action taken upon failure to get a choice of campsite or campground was specified by Users, Cancelers, and Turnaways (*table 9*). Most Users and Cancelers found an alternate campground or another campsite. (An oddity here, probably the result of lack of understanding of the question, is that 63 percent of the Cancelers said they were successful in getting their choice of campsite, even though there was no way they could have determined this if they did not use the reservation.)

Some resource managers were concerned because campers had complained about not being able to pick their campsites. At Yosemite, sites were usually as-

Table 9—Action taken when campers did not get their first choice of either campground or campsite¹

Action taken	Users		Cancelers	Turnaways
	NP	FS		
	Percent			
Changed starting date	9.3	9.8	12.1	
Shortened stay	7.9	4.7	5.2	
Changed campground	36.4	42.0	34.5	
Changed campsite	35.1	34.2	34.5	
Other	11.3	9.2	13.8	
Went to commercial campground				28
Camped outside of established campground				17
Went to				
a State park				17
a NF campground				11
a NP campground				11
Other				17

¹ User sample covers National Parks (NP) or National Forests (FS). Cancelers were sampled only for Yosemite National Park. Turnaways sample was very small—n=20.

signed by attendants although the campers had some choice. Campsites on the San Bernardino National Forest were assigned by computer according to type of camping equipment; the least desirable sites were assigned first. Some adjustments could be made at the campground, however, if space was available and campers requested a substitution. Unfortunately, only about 10 percent of the campers volunteered written comments in response to a specific question on what they liked or disliked about the systems or what they saw as advantages or disadvantages, on the basis of previous experiences at nonreservation campgrounds. Thirteen percent of the Users who did respond disliked not being able to pick their campsite and 9 percent said that was a disadvantage of the system. Nevertheless, over three-quarters of this group were quite willing to make future reservations. Nearly two-thirds of the Users who responded liked being assured of a place to stay, almost half regarded it as an advantage, and nine out of ten in these two groups combined were willing to make campground reservations in the future. It seems likely that campsite assignment by computer or other constraints to free choice are sure to raise some complaints, especially if campers see good campsites going vacant.

Additional responses to more structured questions

suggest a slightly different perspective on campsite selection. Despite the fact that a high percentage of Users did not get their first choice of campsite and a small percentage failed to get their choice of campground, 62 percent of them still enjoyed their trip. On the other hand, 46 percent of the FS Users as compared to 29 percent of the NP Users were disappointed with their trip because they did not get their first choice of campsite or campground. This seems to verify that being assigned a campsite upon arrival at the campground may be more desirable than having one preassigned by computer.

Proportion of Campgrounds to be Reserved

Camper opinions about how many of the Federal-owned campgrounds should be reserved may be useful for guiding management decisions. More than half of the Users and Cancelers believed that three-quarters or more of the total number of campgrounds should be reserved, whereas Potential Users and Turnaways were strongly in favor of reserving half the number or less (*table 10*). Users in the "prefer to plan" group wanted more of the campgrounds placed on a reservation system than did those in the "prefer finding camps as we go" group:

	Planners	Nonplanners
	Percent	Percent
Proportion of campground to be reserved:	(n=558)	(n=200)
All	24.6	9.0
Three-quarters	36.9	15.0
One-half	32.6	34.0
One-quarter	2.2	13.0
None	3.8	29.0

The difference between National Park and National Forest Users is shown in *table 10*. In keeping with the previously noted preference of FS weekday Users for first-come-first-served campsite selection, 22 percent of this group said none of the campgrounds should be reserved. In another study, (U.S. National Park Service 1974), 74 percent of the Yosemite respondents thought more than six Parks should be included in the reservation system. My results agree—a majority of campers preferred most of the campgrounds to be reserved.

Table 10—*Proportion of total number of campgrounds that should be reserved according to camper group*

Proportion of campgrounds to be reserved	NP Users	FS Users	All Users	Cancelers	Potential Users	All campers
	<i>Percent</i>					
	(n=440)	(n=376)	(n=816)	(n=134)	(n=194)	(n=1144)
All	21.1	19.7	20.5	16.4	5.7	17.5
Three-fourths	37.3	23.4	30.9	44.0	9.3	28.8
One-half	33.9	33.2	33.6	29.9	42.8	34.7
One-quarter	3.0	7.4	5.0	3.7	19.6	7.3
None	4.8	16.2	10.0	6.0	22.7	11.7

ENJOYMENT OF CAMPING EXPERIENCE

The vast majority of reservation Users enjoyed themselves: despite problems with both systems, and complaints by some campers, 94 percent said that they had enjoyable stays (*table 11*). This rate of enjoyment did not vary appreciably from one type of camper to another, though Cancelers and Potential Users had stronger positive feelings than Users, and NP Users had more positive feelings than FS Users. It is likely that the lower degree of enjoyment among FS Users reflects dissatisfaction with campsite assignments, as discussed in an earlier section. Even nine out of ten Turnaways said they had enjoyed their stays. They were apparently accustomed to not being able to get into the campground of their choice, and they were generally successful in finding other campgrounds. In general, Turnaways had not camped at the specific campground before and preferred to find campsites as they traveled. Consequently, their enjoyment does not seem to have been affected by the reservation systems.

A helpful response came from 258 campers who had stayed at the *same* campground before and after reservations were instituted: 61 percent said their experience was more enjoyable with reservations than

without; and only 14 percent felt it was less enjoyable (*table 12*). (It should be noted, however, that 21 percent of the FS Users regarded their stay as less enjoyable, against only 6 percent of the NP Users.) Similar results were obtained from those who had stayed at a campground without reservations and then at a different campground with reservations, but the patterns did not vary by agency.

As might have been expected, campers' willingness to make reservations in the future corresponded to their enjoyment (*table 13*). Most Users and Cancelers, but only about half of the Potential Users and Turnaways were willing to make future reservations. On the other hand, the "unwilling" group (28 percent, Potential Users; 25 percent, Turnaways; 12 percent, FS Users) agrees in proportions with the group who prefer to obtain campsites on a first-come-first-served basis.

But enjoyment and willingness to make future reservations should not be attributed solely to success with the reservation systems. Campground characteristics may also contribute to visitor enjoyment and possibly to future acceptance of the systems. More than nine out of ten Users enjoyed their stay and

Table 11—*Enjoyment of camping trip by different groups of campers*

Response to "The trip was enjoyable"	National Park Users	National Forest Users	All Users	Cancelers	Potential Users	All campers
	<i>Percent</i>					
	(n=453)	(n=361)	(n=814)	(n=71)	(n=192)	(n=1077)
Strongly agree	58.9	49.0	54.5	64.8	67.2	57.5
Agree	36.4	42.7	39.2	26.8	28.6	36.5
Neutral	3.3	4.2	3.7	4.2	1.6	3.3
Disagree	0.9	2.2	1.5	1.4	2.1	1.6
Strongly disagree	0.4	1.9	1.1	2.8	0.5	1.1

Table 12—User evaluation of enjoyment of camping under reservation system as compared to other camping experience

Evaluation of reservation camping experience	National Park Users	National Forest Users	All Users
	Percent		
	(n=128)	(n=130)	(n=258)
Same campground:			
More satisfying	67.2	55.4	61.2
No difference	26.6	23.8	25.2
Less satisfying	6.3	20.8	13.6
	(n=139)	(n=86)	(n=255)
Different campground:			
More satisfying	66.7	67.4	67.1
No difference	23.0	24.4	23.6
Less satisfying	10.1	8.1	9.3

Table 13—Campers' attitudes toward making future reservations

Attitude toward making future reservations	Users	Cancelers	Potential Users	All campers
	Percent			
	(n=828)	(n=134)	(n=196)	(n=1158)
Very willing	58.6	63.4	22.4	53.0
Willing	28.1	27.6	33.7	29.0
Neutral	5.8	3.0	15.3	7.1
Unwilling	4.3	4.5	16.8	6.5
Very unwilling	3.1	1.5	11.7	4.4

thought campground conditions, programs, and employee attitudes were good, and a large majority of them enjoyed their stay even though they had complaints about campground facilities or programs. Some (13 percent) of those who complained about cleanliness, and some (12 percent) of those who complained about the employees or about the poor quality of naturalist programs also said they had not enjoyed their stay. And, a small number (5 percent or less) also complained about crowding, traffic, facility conditions, and the frequency of naturalist programs. This combination of complaints with lack of enjoyment suggests that campground characteristics may negatively influence visitor satisfaction and willing-

ness to make future reservations.

To resource managers, some differences between NP and FS Users might suggest where programs need to be strengthened with regard to crowding, naturalist program quality and frequency, campground cleanliness, and employee behavior. The difference between FS Users and NP Users as to crowding (*table 14*) is not surprising; crowding has been a problem at Yosemite for some time. The National Park Service's greater experience with naturalist programs was evident from the 71 percent of its Users who thought program quality was high whereas only 47 percent of the FS Users held that view (*table 14*). Furthermore, 43 percent of the FS Users thought more naturalist programs should be offered at Forest Service campgrounds. Campground cleanliness may be a problem on the National Forests, as suggested by a relatively small number of complaints. Nineteen percent of the FS Users who did not enjoy their stay complained about cleanliness; an additional 12 percent complained about cleanliness but not about their stay. Finally, a small number of Users (11 percent NP and 14 percent FS) who did not enjoy their stay complained about the behavior of employees. Although some of the samples were small, the data suggest that managers should explore possible need for improvement in the areas mentioned.

Table 14—Comparison by agency of evaluations of crowding and naturalist program quality and quantity by Users who enjoyed their stay

Item	National Park Users	National Forest Users
Crowding:	(n=431)	(n=328)
Crowded	30	24
Neutral	22	14
Not crowded	48	62
Program quality:	(n=413)	(n=280)
Good	71	47
Neutral	27	45
Poor	2	8
Program frequency:	(n=408)	(n=299)
Enough	35	16
Neutral	42	41
Not enough	23	43

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Magill, Arthur W.

1976. **Campsite reservation systems ... the camper's viewpoint.** USDA Forest Serv. Res. Paper PSW-121, 15 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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Magill, Arthur W.

1976. **Campsite reservation systems ... the camper's viewpoint.** USDA Forest Serv. Res. Paper PSW-121, 15 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Attitudes and characteristics of campers reached by two Federal campsite reservation programs in experimental use during the summer of 1973 were surveyed. Most campers strongly favored reservations, but preferred that one company sell reservations to all government campgrounds. Questionnaire responses indicated need for a systematic procedure for referring campers to vacant campsites, along with a more effective program of information on the reservation systems. A majority of campers were satisfied to get their first choice of campground, but a few also wanted freedom to choose their campsite. The typical camper was a well-educated, high-income professional or manager, with considerable camping experience. His job allowed him to plan his camping trips in advance and he preferred to do so, though often he planned less than 5 weeks ahead.

Oxford: 907.2

Retrieval Terms: recreation; camp sites; reservation systems; user attitudes; user characteristics.

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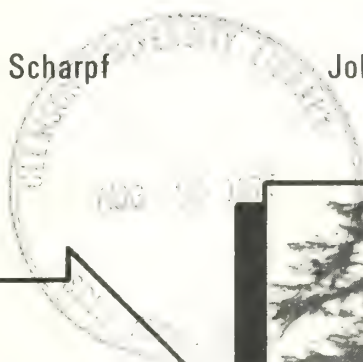
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PACIFIC SOUTHWEST Forest and Range Experiment Station

Population Buildup and Vertical Spread of Dwarf Mistletoe on Young Red and White Firs in California

Robert F. Scharpf

John R. Parmeter, Jr.



CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Methods	3
Results	4
Population Buildup	4
Distance of Vertical Spread	5
Rate of Vertical Spread Compared with Tree Height Growth	6
Discussion and Conclusions	7
Management Implications	8
Literature Cited	9

The Authors

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SUMMARY

Scharpf, Robert F., and John R. Parmeter, Jr.

1976. **Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California.** USDA Forest Serv. Res. Paper PSW-122, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 176.1 *Arceuthobium abietinum*: 181.51:174.7 *Abies* spp.

Retrieval Terms: dwarf mistletoe; population dynamics; epidemiology; vertical spread; red fir; white fir; *Abies concolor*; *Abies magnifica*; *Arceuthobium abietinum*; *Viscaceae*.

Population buildup and vertical spread of dwarf mistletoe (*Arceuthobium abietinum* Engelm. ex Munz.) in young red firs (*Abies magnifica* A. Murr.) and white firs (*Abies concolor* [Gord. and Glend.] Lindl.) were studied in the southern Cascades and central Sierra Nevada. Sixteen red firs and ten white firs, free from an overstory source of infection, were inoculated; all became infected following inoculation. The number of infections per tree resulting from inoculation varied widely, however. After 12 to 15 years, secondary infections developed on only 44 percent of the red firs and on only 40 percent of the white firs. With few exceptions, population buildup of the parasite was greater in red firs than in white firs, but again, the number of infections per tree varied greatly. In general, where population buildup did occur, the infections were clustered within the lower portion of the tree crowns.

Greatest distance of vertical spread, after 12 to 15 years, between the lowest female primary infection and the highest secondary infection was 16 feet (4.8 m). Over the same period of time, however, the mean annual distance of spread of the parasite in test trees was 3 inches (7 cm) or less. No vertical spread occurred in some trees. Rate of vertical spread in red fir was not noticeably different from that in white fir.

Tree height growth was not affected by the para-

site after 12 to 15 years, even in trees with the greatest population buildup. Test trees were growing in height several times faster than the parasite was able to spread vertically. When the ratio of tree height growth to vertical spread is 4 to 1, the proportion of a tree's height infected over time is about 25 percent. With greater ratios of growth to spread, similar to those found in the study, even less of a tree's height becomes infected, assuming tree height growth remains relatively constant.

Several factors account for the slow rate of vertical spread of the parasite. The generation time from seed, production, infection, and development of a mature fruiting plant is 5 years or longer. Also, the dense, persistent foliage of true firs limits the upward dispersal of dwarf mistletoe seeds.

Knowledge of the rate of vertical spread of infection in young firs is important for control of the parasite in managed stands. Our findings suggest that dwarf mistletoe spreads vertically much more slowly than young, vigorous firs grow in height. These parasites will have little impact if firs on good sites are managed for optimum growth consistent with other management considerations. Firs on poor sites, or firs that are not growing well in height for other reasons, will suffer infection buildup, with possible severe impact on the trees.

The dwarf mistletoes are widespread and damaging parasites of true firs in the coniferous forests of California (Scharpf 1964; Scharpf 1969). Two species (*Arceuthobium abietinum* Engelm. ex Munz. f. sp. *magnificae* Hawksw. and Wiens and f. sp. *concoloris* Hawksw. and Wiens) affect red fir (*Abies magnifica* A. Murr.) and white fir (*A. concolor* [Gord. and Glend.] Lindl.), respectively. The mechanism of spread of these parasites from mature stands to adjacent young trees, and the distance covered, are well understood. In brief, ripe seeds of dwarf mistletoe are forcibly discharged from fruits on female plants in large trees and spread about 100 feet (30 m) or less to surrounding smaller trees (Scharpf 1969). Thus, small trees near larger infected ones are constantly exposed to an overhead source of dwarf mistletoe seeds and are often severely infected.

Little is known about population buildup and spread of dwarf mistletoe in small firs when an infected overstory is absent or has been removed. Some information on other conifer species in the West is available, however. Graham (1967) assumed *A. campylopodum* Engelm. in ponderosa pines (*Pinus ponderosa* Laws.) in the Pacific Northwest was able to spread upward an average of about 4 inches (10 cm) a year. Unpublished studies by Strand (1973) for the same host-parasite combination suggest that vertical spread was about 1.5 feet (46 cm) in 6 years or about 3 inches (8 cm) per year. Hawksworth (1969), on the other hand, found that *A. occidentale* Engelm. growing on Digger pine (*P. sabiniana* Dougl.) in California, spread vertically an average of about 2 feet (61 cm) per year over a 16-year period, or at a rate about equal to the height growth of the trees. After 16 years, 1250 infections on test trees had resulted from 20 infections caused by initial inoculation.

Studies of *A. tsugense* (Rosend.) G. N. Jones on western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) in British Columbia (Richardson and Van Der Kamp 1972) suggest a vertical rate of spread approaching that found by Hawksworth (1969). Spread was 12 inches (30 cm) and 23 inches (58 cm) per year in dense and open-growing stands respectively; this was about the same rate as the height growth of the infected trees. The number of new infections increased exponentially with time, doubling about every 4 years over a 20-year period.

For predictions of future impact of dwarf mistletoe in true fir stands, it is important to know both the vertical rate of spread and the rate of population buildup of the parasite in relation to tree height growth. If a tree is able to grow in height and put on healthy crown more rapidly than the crown is being invaded from below by dwarf mistletoe, growth reduction or vigor loss should diminish over time, at least until tree height growth slows.

The objectives of this study of dwarf mistletoe were to determine:

1. Rate of population buildup over several years from an initial number of seed-producing plants.
2. Vertical distance and rate of spread in crowns of young red and white firs.
3. Rate of vertical spread in relation to tree height growth.

METHODS

Studies were conducted at two different areas in California: the Stanislaus National Forest near Pinecrest in the central Sierra Nevada, and the Latour State Forest south of Burney in the southern Cascades. Test trees were located in either pure red fir stands or in mixed conifer stands containing either red or white firs. These areas are described in detail in a previous publication (Scharpf and Parmeter 1967).

On the Stanislaus, a total of 21 trees were selected for study. In 1960, two red firs were inoculated with several hundred seeds; in 1961, three red firs and four white firs were inoculated with several hundred seeds; and in 1963-67, six red firs and six white firs were inoculated for 5 successive years with about 100 to 200 seeds per tree each year.

On the Latour State Forest, five red firs growing within 6 feet (1.8 m) of each other were used as test trees. Trees 1 to 4 were inoculated with a total of 100 dwarf mistletoe seeds in 1958. The remaining tree was not inoculated but was included in the data gathering because of its close proximity to inoculated trees and because some secondary infection did occur in its crown.

All test trees were in areas where dwarf mistletoe was present but out of range of infection from overstory trees. All trees were inoculated with freshly collected seeds each year of inoculation—white firs with

seeds from dwarf mistletoe on white firs, and red firs with seeds from dwarf mistletoe on red firs. Inoculations were made by placing ripe seeds on branches 2 to 6 feet (0.6 to 1.8 m) above ground line. Except for the five red firs on the Latour, all test trees were out of range of infection from adjacent inoculated trees. The trees on both areas ranged in height from 5 to 32 feet (1.5 to 9.8 m) at the beginning of the study.

The test trees were examined periodically, usually once a year, for population buildup and vertical spread of the parasite. Total height of the trees was measured at the beginning and end of the study. Tree height growth was measured for the last 5 years of the study period.

The terms used in reporting results are defined as follows:

Primary infections—Those mistletoe plants resulting from initial inoculation of the test trees with dwarf mistletoe seed.

Secondary infections—All subsequent mistletoe

plants on the inoculated trees, arising from seeds produced by primary infections or other secondary infections.

Maximum distance of vertical spread—The distance measured between the lowest female primary infection in the crown and the highest secondary infection. Because it was not possible to determine the specific origin of the seeds which caused secondary infections, we assumed the greatest possible distance of vertical spread as the maximum. We recognized, however, that it was unlikely that the highest secondary infections actually represented spread from seeds produced by the lowest primary female infection.

Mean distance of vertical spread—The distance computed between the mean height of female primary infections and the mean height of secondary infections. Mean distance was divided by the number of years since inoculation to obtain the *mean annual rate of spread*.

RESULTS

Population Buildup

All trees inoculated on both the Stanislaus National Forest and Latour State Forest became infected with dwarf mistletoe. The number of primary and secondary infections differed greatly among the test trees, however.

On red firs, the number of primary infections ranged from 1 to 72, 12 to 15 years after inoculation. Secondary infections developed on only 7 of the 16 test trees. Striking differences between the Stanislaus and Latour areas (table 1) were noted in the occur-

Table 1—Primary and secondary infections on inoculated red firs and white firs, Stanislaus National Forest and Latour State Forest, California

Host, area, and study period	Test trees	Primary infections			Secondary infections
		Male or unknown	Female	Total	
RED FIR					
Stanislaus N.F.					
1960-75	2	20	10	30	29
1961-76	3	8	14	22	42
1963-75	6	71	48	119	123
Total	11	99	72	171	194
Latour S.F.					
1958-73	5	12	16	28	955
WHITE FIR					
Stanislaus N.F.					
1961-76	4	3	10	13	17
1963-75	6	71	40	111	18

Table 2—Number of new secondary infections observed at intervals following inoculation of red firs and white firs

Host and area	New infections observed after—				Total number of infections
	5 yr	10 yr	12 yr	15 yr	
Red fir:					
Stanislaus N.F.	0	13	147	34	194
Latour S.F.	0	231	267	457	955
White fir:					
Stanislaus N.F.	0	2	25	8	35

rence of primary infections and the buildup of secondary infections. On the Stanislaus, 194 secondary infections occurred over a 12-to-15 year period from an initial 72 primary female infections; on Latour State Forest, 955 secondary infections developed from only 16 primary female infections. This constitutes a buildup at Latour of five times as many secondary infections from only about one-fifth as many primary infections. Thus, the proportion of secondary infections to primary female infections is about 25 times greater on the Latour than on the Stanislaus.

On white firs, the number of primary infections per tree ranged from 2 to 36 and only 4 out of 10 test trees developed secondary infections. A very slow rate of population buildup was noted for dwarf mistletoe on white fir. Only 35 secondary infections resulted after 12 to 15 years from an initial 50 primary female infections.

The reasons why the number of primary infections and population buildup differed greatly among trees and test areas is not known. Possible explanations are discussed later in this report.

Minimum generation time of dwarf mistletoe on firs is 5 to 6 years; in other words, 5 to 6 years are required for a fruit-bearing mistletoe plant to develop from a seed (Scharpf and Parmeter 1967). Therefore we would not expect to see any secondary infections in the present study within 5 to 6 years after initial inoculation of test trees. Except in the red firs at Latour State Forest, very few secondary infections were observed before 12 years after inoculation (table 2).

Distance of Vertical Spread

The maximum distance of vertical spread of dwarf mistletoe was nearly the same on both the Stanislaus and Latour areas. After 15 years, at Latour the maximum spread in any one tree was 14 feet (4.2 m). On the Stanislaus, the spread within a tree was 11 feet (3.4 m) in 12 years. For nearly all trees on both areas,

the spread after 12 to 15 years was considerably less than the maximum reported above.

The mean distance of vertical spread is another way to consider vertical spread. For this value, we compared the mean height of the secondary infections with the mean height of the female primary infections. It may be assumed that not all secondary infections will occur above the primary infections in the crown, although Hawksworth (1961) has shown that seeds of dwarf mistletoe are discharged primarily above the horizontal. Nonetheless, some are discharged downwards and some are likely to be washed onto lower branches by rains following dispersal.

From the combined data for the trees it is clear that at each location, a greater proportion of secondary infection occurred above mean height of primary female infections. For both red fir and white fir on the Stanislaus, about 60 percent of the secondary infections were above the mean height. Certainly the trees at Latour, which bore the greatest number of secondary infections, indicate that spread is predominantly upwards. The height distribution of the secondary infections¹ on the Latour trees was not uniform, however. Ninety percent of all secondary infections at Latour occurred above the mean height (4.1 feet, 1.2 m) of primary infections, but less than 4 percent of all secondary infections were more than 8 feet (2.4 m) above the mean. No secondary infections occurred more than 12 feet (3.7 m) above mean height of the primary infections. Thus, nearly all the secondary infections were tightly clustered within the crowns of the test trees.

¹ Heights of secondary infections at Latour were not measured until 10 to 12 years after the study was begun. As a result, some infections were not recorded because they were missing or tags were lost. We feel, however, that these missing data will not significantly alter the overall results obtained.

Rate of Vertical Spread Compared with Tree Height Growth

The rate at which dwarf mistletoe spreads upward in tree crowns over time in relation to tree height growth is important in predicting future levels of infection and subsequent impact on tree vigor (table 3).

Mean distance and rate of vertical spread were very slow over the duration of the study. Greatest rate of vertical spread occurred after 15 years at Latour but was slightly less than 3 inches (8 cm) a year. In white firs, at the 10-year interval, mean annual spread of dwarf mistletoe was principally downwards or below the mean height of the primary infections.

How does the mean annual rate of vertical spread of mistletoe compare with the rate of height growth of the test trees after 15 years?

In all instances, mean annual height growth of test trees was several times greater than mean annual rate of vertical spread of the parasite (table 3). On the Stanislaus, the ratio of height growth to vertical spread varied markedly among the red firs and white firs with secondary infections. For red firs, the smallest ratio found was 4 to 1 and the largest 18 to 1; whereas for white firs, the range in ratios was 8 to 1 and 35 to 1. The reasons for the wide variation in ratios are not known and cannot be explained on the basis of differences in tree height growth or differences in levels of dwarf mistletoe populations among individual trees.

At Latour State Forest, the height growth/spread ratio was less variable among trees than on the Stanislaus. The rate of height growth ranged between five and seven times that of vertical rate of spread.

The proportion of a tree's height that is infected by dwarf mistletoe depends on the ratio between tree height growth and vertical rate of spread of the parasite. Regardless of what percentage of a tree's height is initially infected, over time the proportion of the

height infected approaches a constant, assuming the ratio of height growth to vertical spread remains the same.

This principle might be best illustrated by a hypothetical model (figure 1). Using data based on the results obtained in this study, we will assume that two 30-year old trees, 20 feet (6.1 m) tall, with full

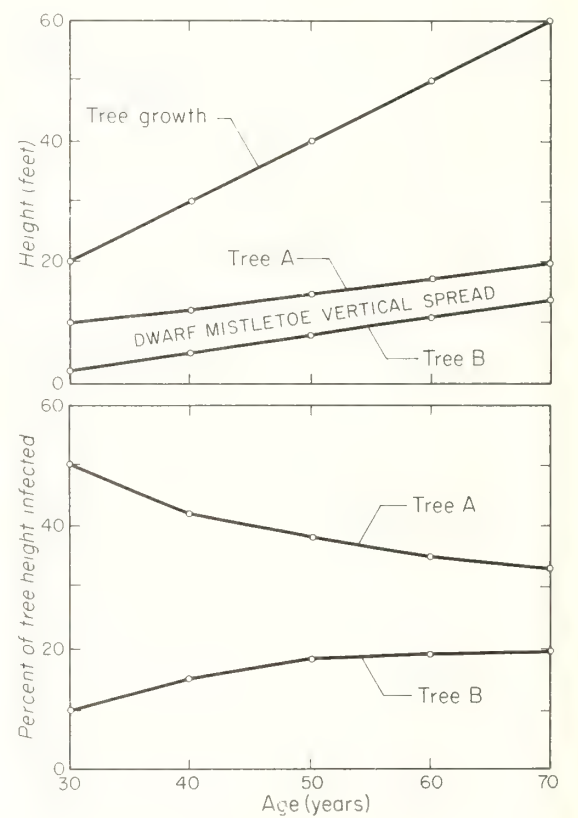


Figure 1—Young, vigorous firs outgrow the vertical spread of dwarf mistletoe. Above, in two hypothetical trees, growth-to-spread ratio is 4 to 1. Below, percent of trees infected increases or decreases, depending on proportion of tree infected at age 30.

Table 3—Tree height growth rate and annual rate of vertical spread of dwarf mistletoe in red and white fir test trees at intervals following inoculation

Host and area	Mean annual tree height growth rate	Mean annual rates of vertical spread of mistletoe—			Ratio of height growth rate to vertical spread at 15 years
		10 yr	12 yr	15 yr	
Red Fir:		— Feet —			
Stanislaus N.F.	0.7	0.08	0.13	0.06	12/1
Latour S.F.	1.5	0.17	0.12	0.24	6/1
White fir:					
Stanislaus N.F.	0.7	-0.23	0.06	0.08	9/1

crowns, are growing in height a foot (30 cm) a year. In tree A the lower half of the crown is infected—in tree B only the lower 10 percent. Dwarf mistletoe spreads upwards at the rate of 3 inches (8 cm) a year; thus we have a growth-to-spread ratio of 4 to 1. When we plot tree height infected against tree age for tree A, we find the percentage of crown infected diminishes. Conversely, when we plot tree height infected against tree age for tree B, we find the percentage of crown infected increases. In both trees, however, the level of infection over time is approaching 25 percent. The relationship holds true for trees of all sizes and ages as long as a growth-to-spread ratio of 4 to 1

remains constant. In practice, this ratio is not likely to remain constant over the years. We feel, however, that the model demonstrates the relationship between tree height growth and vertical spread of dwarf mistletoe and the proportion of tree crown infected over time.

If we have growth-to-spread ratios more like those found in the study (6 to 1 or 12 to 1), then over time a much smaller proportion of tree's height will be infected. Also, as trees grow older, less of their total height is composed of living crown. Therefore, the percentage of living crown infected will be even less than the percentage of total tree height infected.

DISCUSSION AND CONCLUSIONS

Results of the present study suggest that vertical spread of dwarf mistletoe in red and white firs in California averages less than about 3 inches (8 cm) a year. Our results also indicate that *A. abietinum* spreads vertically at a slower rate than any of the other dwarf mistletoe species and host combinations investigated to date (Graham 1967, Hawksworth 1969, Richardson and Van Der Kamp 1972, Strand 1973).

Several factors may account for the slow rate of spread. First, *A. abietinum* has a rather long generation time between seed dispersal, infection, and subsequent development of infections to the mature, fruiting stage. This period has been shown to be at least 5 to 6 years and may be even longer (Scharpf and Parmeter 1967; Parmeter and Scharpf 1972). Second, the characteristic growth of the branches and foliage of true firs limits distance of spread. The branches of young firs characteristically arise in quite regular tight annual whorls from the main trunk. Also, the foliage on true firs is retained for many years rather than a few years, as in the pines, for example. The physical barrier created by the dense foliage and branches in a whorl is very effective in intercepting seeds dispersed by female infections on lower branches. Thus, most vertical dispersal of seeds of dwarf mistletoe on young firs is restricted to one or two whorls above the fruit-bearing plants. As a result, even high populations of dwarf mistletoe tend to be localized within the crowns of firs rather than distributed throughout much of the crown as they are in the more sparsely foliated, irregularly branched Digger pine (Hawksworth 1969). A third factor in the slow spread evident in our study may be that not every year is favorable for fruit production, seed germination, and infection by dwarf mistletoe. At least

one fungus parasite periodically destroys the shoots and fruits of dwarf mistletoe on firs when climate conditions are favorable for the disease (Parmeter and others 1959). Also, certain climatic conditions in themselves, we feel, often limit fruiting, germination, and infection. As a result, population buildup and to some degree vertical spread vary considerably from one year to the next.

The variation in numbers of secondary infections within individual trees does not appear to be necessarily related to the number of primary seed-producing dwarf mistletoe plants in a given tree. At Latour, the test trees may have been inherently more susceptible to infection than those on the Stanislaus, or climatic conditions may be more favorable for infection at Latour. Even on the Stanislaus, unexplainable wide differences in numbers of primary and secondary infections were recorded. Further studies are needed.

Because this study extended over a period of 12 to 15 years, we can assume that secondary infections in the crowns of the test trees were produced by seeds from both primary and first-generation secondary infections. What the rate of buildup will be in the future is not known and needs to be further investigated. We can anticipate, however, that perhaps the rate of population buildup will increase as more seed-bearing plants among succeeding generations of plants also begin to bear fruit. On the other hand, mortality of dwarf mistletoe plants as a result of natural pruning of the lower branches as trees grow in height will lower the population levels of the parasite and reduce the proportion of the live crown infested. Additional mortality of dwarf mistletoe from squirrel feeding, the fungus *Cytospora abietis* (Scharpf and Bynum

1975), and other causes will also aid in keeping populations in check.

Rate of vertical spread should not increase markedly over time, however, unless distance between annual branch whorls increases markedly. Vertical spread appears to be regulated more by the physical barrier imposed by the branches and foliage of the annual whorls than by population levels of the parasite. Even if mean annual rate of spread increases as a result of the greater distance between annual whorls, the ratio between tree height growth and vertical spread of dwarf mistletoe should remain more or less constant.

Measurements of tree height growth at Latour for 1971-73 suggest that the buildup of the parasite in the lower crown is having no noticeable impact on

growth. All test trees were growing in height over these later years at a mean annual rate comparable to that measured for the years 1958-70. This is in agreement with studies by Hawksworth (1961) that have shown that little growth reduction or impact occurs in pines if dwarf mistletoe is restricted to the lower third to one-half of the tree crown. We have found from studies in progress that the same phenomenon applies to true firs.

We envision that the vertical spread rate will approach that of height growth in (1) older fir trees that have reached maturity and are growing very slowly in height, and (2) low vigor trees growing slowly in height and with very thin foliage or irregularly branched crowns, for example, suppressed trees or trees on poor sites.

MANAGEMENT IMPLICATIONS

Results of the study have important implications for management and control of dwarf mistletoe in young-growth red fir and white fir stands. The principle behind the management approach is that *dwarf mistletoe populations will not spread and build up over time beyond a certain proportion of the tree height in young trees with good height growth and in the absence of overstory infection*. Several important points should be considered in dwarf mistletoe management or control decisions:

1. Dwarf mistletoe spreads vertically in crowns of young red and white firs an average of 3 inches (8 cm) or less per year.

2. Young, vigorous red and white firs will suffer little growth impact if dwarf mistletoe can be restricted to the lower half of the tree's height (or crown).

3. A tree growing an average of 1 foot (30 cm) a year will have a ratio of height growth to vertical spread of about 4 to 1 or more. This ratio is adequate to ensure that no more than about a quarter of a

tree's height and even less of its living crown will be infected with age until the tree reaches maturity and slows in height growth.

4. Even trees infected throughout a substantial portion of the crown will become proportionately much less severely infected if a growth-to-spread ratio of 4 to 1 or greater can be achieved.

The key to dwarf mistletoe control in young fir stands is the same as good silvicultural management of healthy, young fir stands. Use whatever means necessary to insure good height growth of young stands consistent with proper stocking levels and other management considerations.

Young trees on poor sites, or trees that for other reasons are not growing in height, are likely to experience buildup and impact from these parasites. Also, once height growth slows in vigorous, older trees, an increase in the proportion of crown infected, and in the impact of the dwarf mistletoe on tree growth, can be expected.

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Scharpf, Robert F., and John R. Parmeter, Jr.

1976. **Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California.** USDA Forest Serv. Res. Paper PSW-122, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Rate of population buildup of dwarf mistletoe, *Arceuthobium abietinum* Engelm. ex Munz., was slow in most small red firs and white firs 12 to 15 years after inoculation with the parasite. Where population buildup did occur, it remained clustered in the lower portions of tree crowns near inoculation sites. Maximum distance of vertical spread was 16 feet (4.8 m), after 15 years. The mean annual rate of vertical spread of the parasite in 12 to 15 years was 3 inches (7 cm) or less in test trees. No vertical spread occurred in some trees. Rate of vertical spread was much slower in all trees than the mean annual height growth of vigorous young red or white firs. Therefore, the test trees were outgrowing the spread of dwarf mistletoe within tree crowns. Vertical spread rate and rate of tree height growth together determine the proportion of tree crown that will be infested at a given time after inoculation.

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Scharpf, Robert F., and John R. Parmeter, Jr.

1976. **Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California.** USDA Forest Serv. Res. Paper PSW-122, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Rate of population buildup of dwarf mistletoe, *Arceuthobium abietinum* Engelm. ex Munz., was slow in most small red firs and white firs 12 to 15 years after inoculation with the parasite. Where population buildup did occur, it remained clustered in the lower portions of tree crowns near inoculation sites. Maximum distance of vertical spread was 16 feet (4.8 m), after 15 years. The mean annual rate of vertical spread of the parasite in 12 to 15 years was 3 inches (7 cm) or less in test trees. No vertical spread occurred in some trees. Rate of vertical spread was much slower in all trees than the mean annual height growth of vigorous young red or white firs. Therefore, the test trees were outgrowing the spread of dwarf mistletoe within tree crowns. Vertical spread rate and rate of tree height growth together determine the proportion of tree crown that will be infested at a given time after inoculation.

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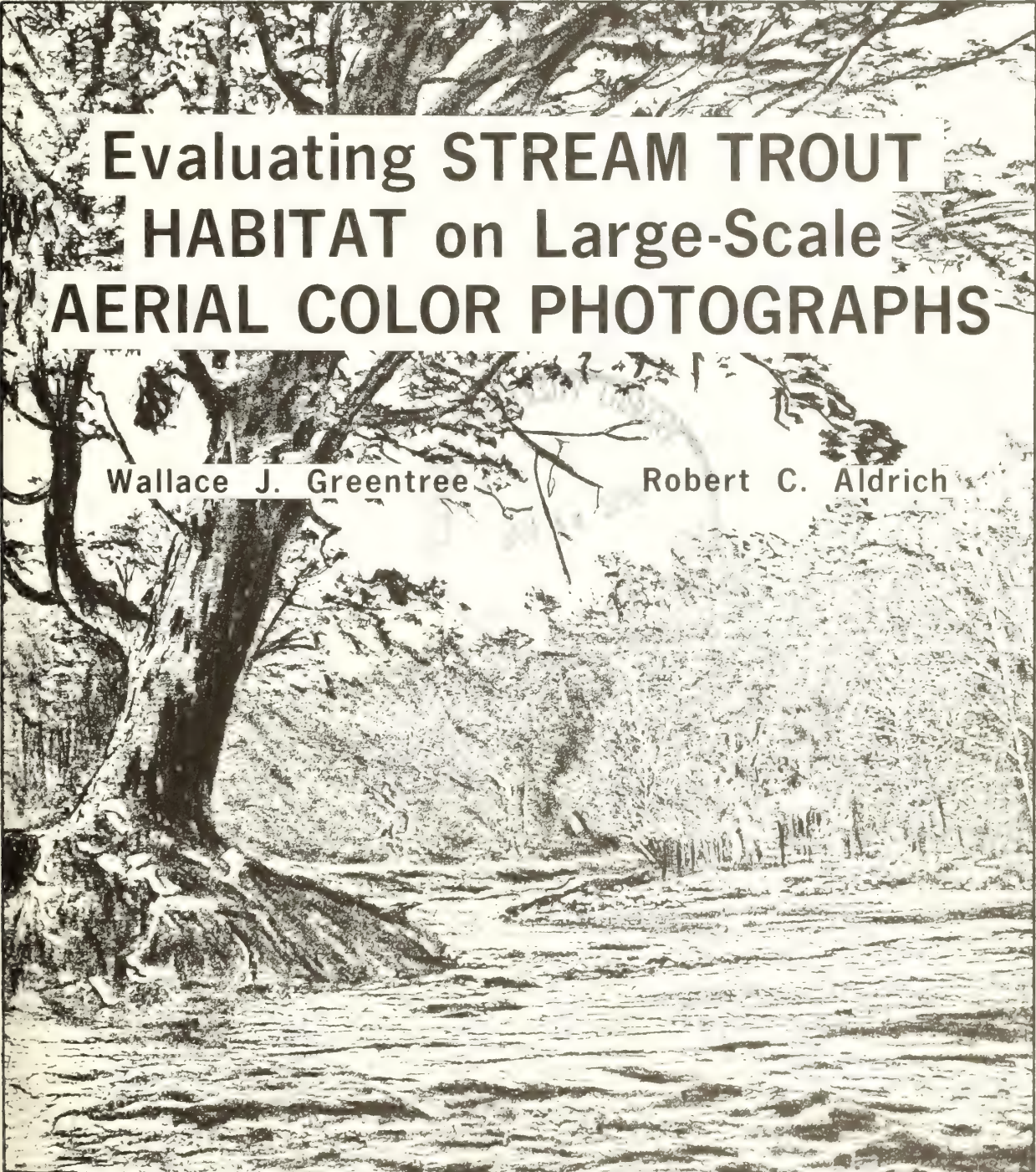
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Evaluating STREAM TROUT HABITAT on Large-Scale AERIAL COLOR PHOTOGRAPHS

Wallace J. Greentree

Robert C. Aldrich

CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Methods	3
Aerial Photography	3
Photo Analysis	4
Results and Discussion	11
Interpretation of Habitat Conditions	11
Accuracy of Interpretation	12
Accuracy of Measurements	13
Habitat Evaluation Cost	17
Conclusions	18
Appendix	
A. Helpful Formulas	19
B. Procedures for Determining Degree of Shade on a Stream	20
Literature Cited	21

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SUMMARY

Greentree, Wallace J., and Robert C. Aldrich.

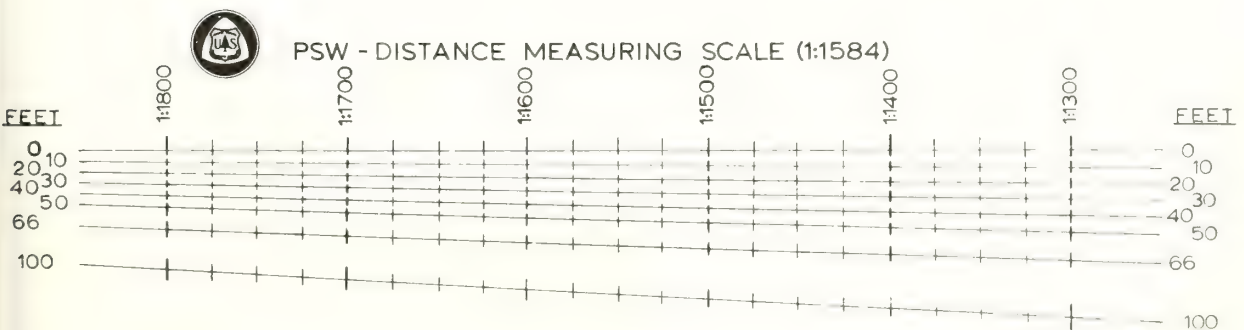
1976. **Evaluating stream trout habitat on large-scale aerial color photographs.** USDA Forest Serv. Res. Paper PSW-123, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 587.6:156.7-147.

Retrieval Terms: trout habitat; photointerpretation; habitat evaluation.

Large-scale aerial color photographs were used to evaluate trout-habitat conditions on a portion of Hat Creek in northern California. Two 70-mm Maurer KB-8 cameras with Anscochrome D-200 and Ektachrome Infrared, type 8443, were flown at three scales: 1:600, 1:1584, and 1:6000. Stream and streambank conditions were studied on the photographs and defined in terms of habitat evaluation requirements. A photointerpretation test showed that 92 percent of the habitat conditions could be identified correctly on the normal color photographs. Changes in stream vegetation as a result of rehabilitation efforts could be detected and measured on photographs taken 1 year apart. A scanning microdensitometer was used to see if film density was

correlated with water depth; the correlation on normal color film was 76.4 percent and the correlation on color infrared film was 73.5 percent. Estimates of water depth made by parallax measurements resulted in poor accuracies. Shadow length measurements of streambank vegetation converted to brush and tree heights were 86 percent accurate. A technique to measure the degree of shade created on a stream by streambank vegetation is described and evaluated. Two photointerpretation aids were developed: a scale of particle sizes to categorize bottom types, and a distance-measuring aid to check actual photograph scales. The cost of large-scale color evaluation of stream trout habitat was estimated to be from \$200 to \$250 per mile of stream.



The PSW distance-measuring scale was devised for use in determining actual photographic scale of each triplet. The scale, which is printed on acetate, is placed over the 100-foot ground marker panels on the photographs and moved until the 100-foot index mark on the scale matches the distance between panels. The photo scale is read opposite the index mark.



Figure 1—The dashed line across the stream marks one transect; the two crosses on the streambank are 100 ft apart and are the ground marker panels. The black-and-white photo was reproduced from the original 1:1584 color infrared transparency and enlarged three times.

In management of wildlife, evaluation of streams as trout habitat may be required, to determine when conservation efforts should be made. Transect methods requiring instream measurements of habitat parameters are presently used for such evaluation. Instream measures are time consuming and expensive and may not provide enough data for good habitat evaluation. New developments in stream habitat sampling with large-scale aerial color photography, however, may improve measurements for some parameters and give more information at a lower cost. These photo sampling techniques, together with some ground measurements, can provide baseline data of the habitat under various flow conditions.

In fall 1968 and 1969, large-scale aerial color photographs were taken of a 3.5-mile portion of Hat Creek, in northeastern California. The photographs were studied to determine their usefulness for evaluation of stream trout habitat. The study site, near the town of Burney, is a crystal-clear stream, which meanders through meadows and pine and oak-covered hills at about 3000 feet elevation (914 m), and is famous for trout angling. By 1968, however, the

stream had become overpopulated by rough or non-game fish which limited the trout populations. Rehabilitation efforts in fall 1968 and adherence to stream management guidelines since then have made this portion of Hat Creek a productive trout stream again (Barnhart 1970).

The aerial photo coverage of Hat Creek included color and color-infrared photographs at three different scales (1:600, 1:1584, 1:6000). The 1968 series were taken before a joint effort was made by Federal, State, and private conservation organizations¹ to rehabilitate the stream. The 1969 series were taken to assess the rehabilitation program.

Measuring trout habitat conditions on large-scale color photography is a relatively new application of remote sensing. It has special requirements and presents new problems. This paper looks at these requirements and problems and (1) outlines areas where photographs will be most beneficial, (2) describes techniques and aids for measuring habitat conditions, and (3) presents the potential user with enough information to enable him to make his own decision—"can large-scale color photography help me evaluate trout habitat?"

METHODS

Aerial Photography

Most of the methods presented in this paper were originally designed for use in forestry. In applying them to the special problem of trout habitat evaluation, we sometimes tried more than one method. For some measurements, we had to design and make specific photo aids.

Two photographic flights were made over the Hat Creek study site. The first, on October 8, 1968, was made immediately after the stream had been chemically treated to reduce undesirable fish and had been restocked with trout. The second flight, a year later on October 8, 1969, was designed to allow us to evaluate changes or potential changes in stream habitat that were associated with rehabilitation efforts. The two sets of photographs were used for both conventional photointerpretation and for automated interpretation using optical film density.

The photography was obtained using two Maurer² KB-8 70-mm cameras (with 6-inch focal-length lenses) mounted in a Forest Service Aero Commander. Two color films, Anscochrome D/200 (color) and Ektachrome Infrared, type 8443 (CIR), were exposed simultaneously with 60 to 80 percent overlap for stereoscope viewing at three relatively large scales—1:600, 1:1584, and 1:6000.

In preparation for the photographic flight, we located four study transects along the stream banks. Before each flight, at each transect location, two sets

¹ California Cooperative Fishery Unit, U.S. Fish and Wildlife Service; Forest Service, U.S. Department of Agriculture; California Department of Fish and Game; Pacific Gas and Electric Company; and Trout Unlimited.

² Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

Table 1—Trout stream habitat criteria¹ in California

Instream Conditions	
Aquatic vegetation	Cover types
Emergent	Logs, debris, and boulders
Submergent	(above water)
Bottom types	Logs, debris, and boulders
Silt	(below water)
Sand	Man-made structures
Gravel, fine (>1.0 inches)	Shade (overhead)
Gravel, coarse (1 to 3 inches)	Turbulent surface water
Rubble, fine (3 to 6 inches)	Surface velocity
Boulders (12+ inches)	Slow—less than 1.0 f/s, surface smooth
Bedrock	Fast—greater than 1.0 f/s, surface rough
Plant waste	
Water depth	General habitat
Less than 0.5 ft	Pools
0.5 to 1.5 ft	Runs
1.5+ ft	Riffles

Streambank Conditions

Bank cover types	Bank types
Deciduous (d), evergreen (g)	Low, undercut
Weeds and shrubs; 0 to 4 ft	Low, no undercut
Trees; 15 to 50 ft; 50 to 100 ft; 100+ ft	High, undercut
Annual grasses, brown or green	High, no undercut
Gravel, rocks, boulders	Eroded bank
Bare soil	
Bedrock	
Overhanging vegetation or debris	

¹ Based on Lagler 1956, White and Brynildson 1967, and correspondence with Dr. Roger A. Barnhart, Leader, California Cooperative Fishery Unit, Humboldt State College, Arcata, Calif., 1969, and with Fisheries Research Center, Division of Wildlife, Fort Collins, Colorado, 1973.

of 10-foot panel markers were placed for later photographic scale determinations.

Photo Analysis

After processing the 1968 films, we used the resultant color and CIR transparencies to locate the four transects which would represent trout habitat conditions along the stream (*fig. 1*). Three overlapping photographs for each transect were removed from the roll of film and mounted in clear acetate

envelopes for stereoscopic viewing. Points marking the ends of transects were pinpricked on the triplets, to help in locating the transects on the ground as well as to locate the scan line for optical film density measurements.

Defining Habitat Conditions

In preparation for the photointerpretation, we needed to define important features that could be measured on a vertical photograph. A review of the literature and an examination of the large-scale photographs helped us to separate these features into two broad groups—instream conditions and streambank conditions (*table 1*).

Instream conditions are important criteria because the stream provides trout with primary needs such as food, shelter, and proper conditions for reproduction. During the day and under the cover of darkness, trout choose shelter spots in the stream for rest, protection, and feeding. Stream habitats also affect trout stream insects. Most choose to live in shallow, swift riffles, and their distribution is dependent on bottom types, water depth, and water velocity.

Streambank conditions are important criteria because the bank provides cover. Bushes, trees, and the streambanks themselves afford shade that not only shelters the fish, but also affects water temperature. According to Needham (1969), "Water temperature is probably the most important single factor governing the distribution of all species of trout." Streambank vegetation also helps control erosion and influences the supply of land insect and plant litter that enters the stream.

Once the habitat conditions had been defined, conventional photointerpretation techniques were used to determine how these conditions could be measured. The photographs were examined on a light table with the aid of an Abrams Stereoscope at both two and four times magnification (*fig. 2*), in order to better define the physical and biological features of trout habitat that could be seen on each color film at each photographic scale. We also determined that the time lapse between photographic flights allowed us to see changes in habitat conditions 1 year after the reduction of nongame fish populations.

Instream Conditions—Aquatic vegetation was identified by appearance and color. Bottom types were classified by size of particles and physical appearance. A scale of particle sizes was developed (*fig. 3*) as an aid in categorizing bottom types into one of four size classes: 1 to 3 inches, 3 to 6 inches, 6 to 12 inches, and 12 inches or more. The transparent film aid was placed on the photo image in question and moved



Figure 2—An Abrams stereoscope on a Richards light table was set up for stereoscopic viewing of 70-mm color transparencies.

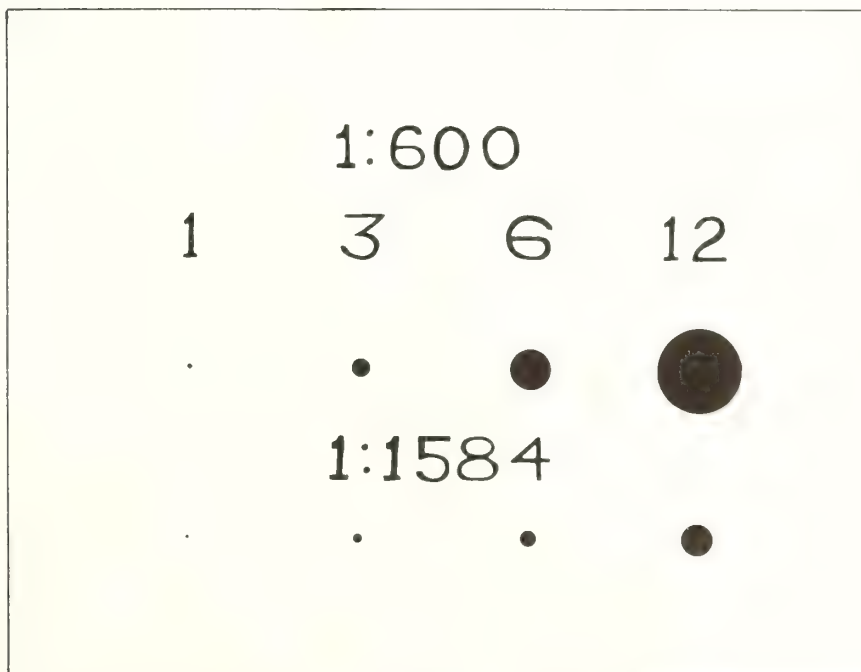


Figure 3—A particle-size scale was devised for categorizing stream bottom types into one of four size classes. The scale shown here is 22.5 times larger than the scale used for photointerpretation.



Figure 4—The Photometric Data Systems (Model 1000) scanning microdensitometer and data acquisition system.

until the particle size on the film equaled the average condition on the stream bottom.

Water depth estimates were made with parallax measuring devices designed for use on 70-mm film. Two devices were tried—a parallax bar and a parallax wedge. With either method parallax readings are taken on the photo at one point on the water surface and another on the bottom of the stream. The difference between the two readings, or differential parallax, is used in the parallax formula (see Appendix A) to obtain the value for water depth.

Another method tried for estimating water depth requires measurement of optical film densities. In this phase of the study we used an automatic scanning microdensitometer (MDT) (*fig. 4*) to measure optical film density along each of the four transects on 1:1584 color and CIR transparencies. Each transparency was placed in turn on the MDT and positioned so that scans would be made between the points marking the transects. Then the MDT was programed to record automatically the film density along the

transect lines. Each transect was scanned four times—once without a filter (clear), and once each with red, green, and blue MDT filters (Wratten 92, 93, and 94). “Normalized” film densities³ were used in regression analysis techniques to test the hypothesis that water depth can be predicted from optical film density.

Conventional photointerpretation techniques were used for identifying cover types, surface velocity, and general habitat types on the four-transect study area.

Stream Bank Conditions—Shoreline vegetation, such as bushes and trees, provides most of the shade cover on the stream. Also, certain bushes and trees help to govern the quantity of land insects and plant litter entering the stream. The procedure which resulted from our effort to determine which bushes and trees contribute to these relationships is described in

³These were computed by subtracting the film density measured with unfiltered white light from the red-, green-, and blue-filtered film densities. This lessens the effect of exposure differences within and between photos.

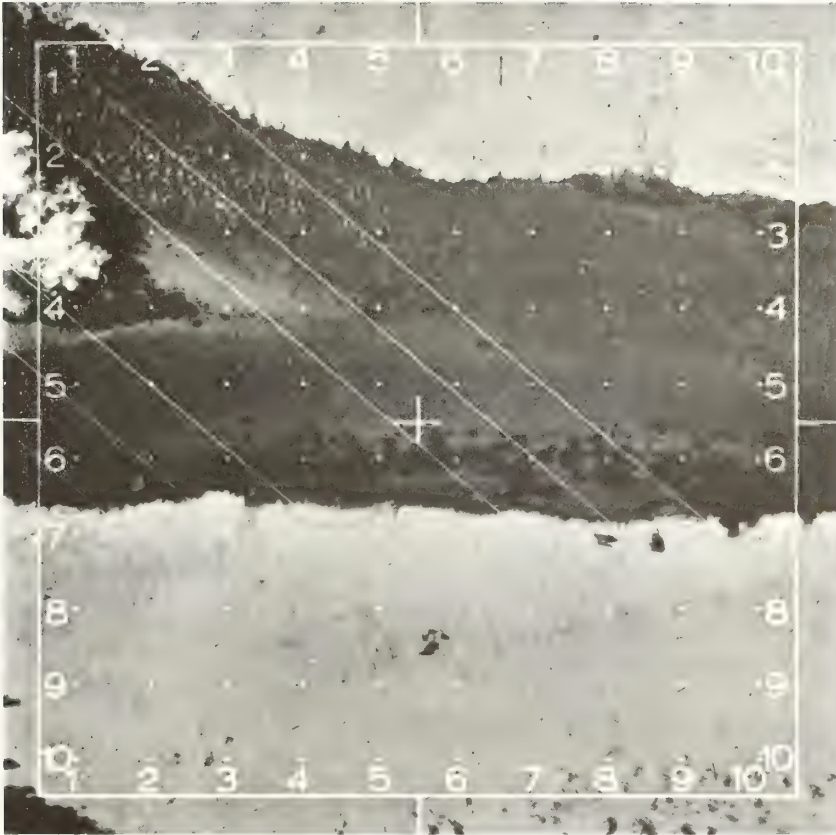


Figure 5—A 100-dot grid was overlaid on each triplet for interpretation of habitat conditions. This black-and-white photo was reproduced from a color infrared transparency and enlarged two times. Diagonal lines through the center of the picture are power lines.

Appendix B. Essentially, it required finding values for solar azimuth and solar altitude for the time, date, and latitude of photography. The solar values were used for determining shadow position and tree heights from length-of-shadow measurements on the photographs. The solar values were expanded for every hour of the day. The expanded solar values were used with stream direction to determine which bushes or trees affected the stream habitat throughout the day. Bushes and trees were identified on the photographs as either evergreen or deciduous, and their crown sizes were measured as an aid in the overall evaluation of shadow effects.

The remaining streambank vegetation types—bare soil, gravel, rocks, boulders, and grasses—were classified by conventional interpretation techniques.

Bank types were classified by interpretation of form, shape, and height. Heights were estimated by photo comparisons and by measuring with a parallax bar.

Photointerpretation Test

An interpretation test was made to classify trout habitat conditions according to the eight major classes listed in *table 1*. Only the 1:1584 color photographs from 1968 and 1969 were used in this initial test.

One interpreter examined trout habitat classes at each of 100 dots on a grid template which overlaid the center photograph of the photo triplet for each of the four transects (*fig. 5*). The scale of each triplet was determined by measuring the distance between ground marker panels with the PSW distance-measuring

scale (*fig. 6*). The area immediately under and within a 3-foot radial distance of a grid point was examined to determine if the point was in water or on the streambank. Each point was then classified by the appropriate habitat condition identified in this study.

Ground Measurements

Using the 1968 photography, we located the four sample transects and marked them with a metal stake on each bank of the stream. Two men then waded the stream and recorded bottom types and water depths at 1-foot intervals across each transect. The clarity of the water allowed us to determine the bottom types by physical form. Water depths were measured with a 0.01-foot calibrated stick. Also, we recorded cover classes, such as a submerged log, at the 1-foot measuring point.

Total heights of 48 bushes and trees located within the study area were measured with a Spiegel-Relaskop.⁴ These measurements were used to check the accuracy of heights estimated using both parallax-measuring devices and shadow-length measurements.

To verify the photo habitat classifications, 95 points—representative of major habitat classes—were checked in the field. Ground photographs of these sites were used with aerial photographs to make interpretation aids (*fig. 7*).

⁴The "Spiegel-Relaskop," invented by Dr. W. Bitterlich of Austria, is a small (14-ounce), ruggedly constructed hand instrument. This single instrument can be used to make optical measurements of tree basal area, tree height, tree diameter, tree form class, and distance.

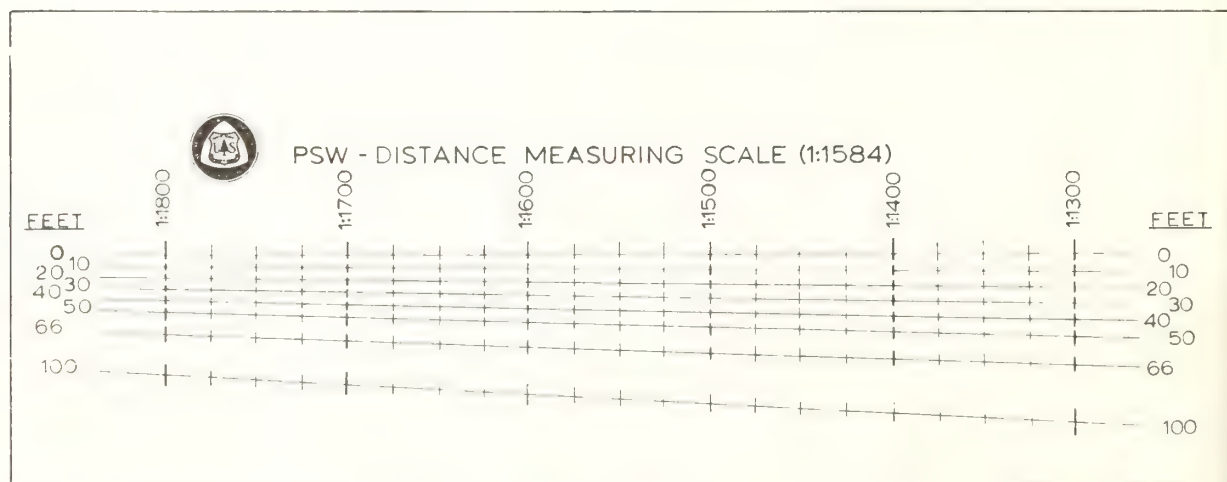


Figure 6—The PSW distance-measuring scale was devised for use in determining actual photographic scale of each triplet. The scale, which is printed on acetate, is placed over the 100-foot ground marker panels on the photographs and moved until the 100-foot index mark on the scale matches the distance between panels. The photo scale is read opposite the index mark.

STREAM CONDITIONS



SHELTER



SHELTER

STEREO PAIR



STREAM BANK CONDITIONS



Figure 7—Four trout habitat classes are shown on this interpretation aid.

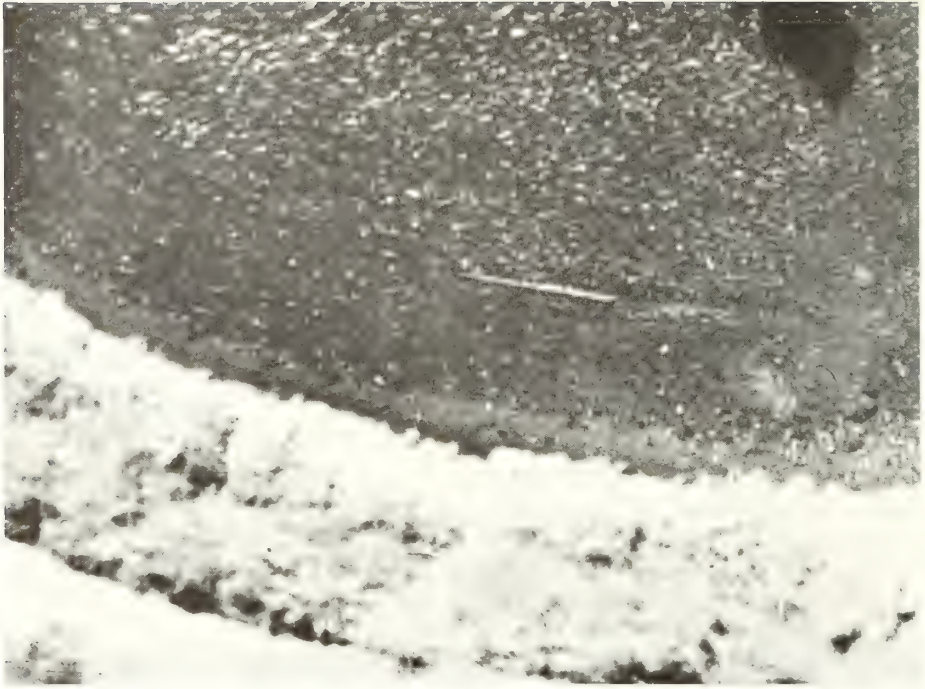


Figure 8—Photographs taken 1 year apart (1968, *top*, 1969, *bottom*) show the increase in aquatic vegetation following rehabilitation efforts. The black-and-white photographs were made from color infrared transparencies and enlarged 2 times.

RESULTS AND DISCUSSION

We have evaluated two color films and three photographic scales for classifying the limited stream trout habitat conditions present in four small study sites. Although this study was limited in scope, we feel the techniques and results reported here justify further investigation, particularly for evaluating high-use, high-value streams.

Interpretation of Habitat Conditions

Large-scale aerial photographs show some interesting possibilities for habitat evaluations. We found that the 1:1584 normal-color photographs gave the best overall results. On properly exposed color photographs at this scale, the interpreter can readily discern the form, shape, and color of instream and stream-bank features.

Instream Features

At the 1:1584 scale, aquatic vegetation was easier to identify on the CIR photographs than on normal-color photographs. Healthy vegetation appears bright red on these photographs, so that it is possible to identify beds of vegetation and determine their vigor. Increases in vegetation 1 year after removal of non-game fish were quite evident when 1968 and 1969 photographs were compared (*fig. 8*).

It was possible to describe aquatic plants with greater detail from the 1:600 photographs. This scale would be most useful to a fisheries biologist because of the amount of visible details. For instance, the trout-cover value and the quality of submergent and emergent aquatic plants can be assessed. Also, since certain types of trout stream insects are associated with aquatic vegetation, the biologist can subsample these plants in the stream for insect population estimates, with reference to photographs of the total aquatic vegetation present.

At 1:600, color photographs provided a more detailed description of stream bottom types than of the 1:1584 scale. Where the water surface was smooth and was not obscured by overhanging vegetation or shade, we were able to recognize the general types present in Hat Creek. The particle-size scaling aid (*fig. 3*) was used to categorize these types into size classes. When the bottom type is known, certain inferences about insect fauna can be made: for instance, certain bottom types provide habitat for larvae and nymphs of stream insects which are trout

food, and trout food productivity varies with bottom type.

Water depths could be estimated by parallax measurement methods on those portions of the stream which did not have rough surfaces and were clear of overhanging vegetation and shade. Our most useful estimates were made on 1:1584-scale photographs that had been properly exposed for the stream—1968 color and 1969 CIR were best in this respect.

Other underwater features that can be seen best at the 1:600 scale include submerged logs, brush, limbs, and boulders. Root mats at the sides of the stream and on tree isles in the stream were also observed. These features can be classified and evaluated for their value as cover for trout and habitat for certain trout stream insects.

On those portions of Hat Creek where the stream width exceeded 100 feet, the 1:600 photographs did not give bank-to-bank coverage. This lack of coverage made it difficult to fully assess the bottom and underwater cover types. Better planning of photographic missions can reduce this problem, and two flight lines which sidelap may be required.

Surface velocity classes were best estimated at the 1:1584 scale on the CIR photography, but we were also able to classify them at the 1:6000 scale. The two classes (fast and slow) were inspected for water surface characteristics. Water classified as "fast" has a rough, rippled appearance with many white reflecting surfaces interspersed with clear water. "Slow" water has a smooth surface and appears clear. Reflections from rough surface water in full sunlight are more apparent on CIR than on color photographs. On CIR film, however, no surface details are visible in dense shadow (black) areas. Surface characteristics of slow and fast water types can be misleading if winds are affecting these surfaces at the time of photography. Wind effects on a slow water surface, such as a pool, may give it the appearance of a rough water surface.

After bottom types, water depth, cover types, and surface velocity types have been determined, the interpreter can further categorize the stream into general habitat types such as pools, runs, and riffles. Pools are habitat types of considerable depth for the size of the stream and have slow-flowing water with smooth surfaces. Within the study area, pools were difficult to classify because of the general character of lower Hat Creek. Run and riffle habitats are defined in the Hat Creek Management Plan (Gerstung

1975) as follows: "The . . . 'run' habitat . . . averages about 115 ft in width, 4-5 ft in depth and . . . is characterized by grassy undercut banks, a bottom of sand and silt with scattered gravel patches, boulders and sunken logs, and an abundance of rooted aquatic plants. The riffle section . . . is wider (mean width 126 ft), shallower (1.5 to 3 ft deep) and characterized by . . . faster velocities . . . [a] bottom . . . of rubble, boulders, some gravel and sparse plant growth." By recognizing these categories, the interpreter can assess the habitat in terms of shelter, resting spots, feeding spots, and spawning grounds. The 1:1584-scale photographs, both color and CIR, were useful for defining pools, runs, and riffles. We preferred the color photographs because surface details in shadow areas can be seen better. Color film is a better penetrator of water (Fritz 1967) and has a greater exposure latitude, resulting in better shadow penetration.

Streambank Features

It was easier to identify undercut banks on CIR photographs than on normal-color photographs on all three scales of photography. On the CIR photographs, moist grasses, which occur along undercut banks, appear in hues of bright red, and are thus more apparent than they are in the green hues of normal-color photographs. Undercut banks are important because they offer excellent cover for trout during the day.

The 1:1584 color photographs are adequate for distinguishing between conifers, deciduous hardwoods, and brush. Delineation of these vegetation types makes possible assessment of cover value for trout as determined by seasonal shade. Also, plant litter entering the stream can be evaluated: the plant litter from deciduous species is greater than from evergreen species. A portion of these wastes becomes habitat and a source of food for certain bottom-dwelling insects.

Bank features found along margins of the stream may be part of streambank conditions or part of instream conditions. Visibility of photographic details of these features depends on the scale and type of photography used. A scale of 1:600, color, was best for identifying those at the water line, such as overhanging limbs and branches, debris washed up on the bank, undercut banks, cattail marshes, and mouths of tributaries. Bank cover types such as annual grasses, rocks, gravel, sand, and bare soil can be assessed at the stream margins for signs of erosion or other possible causes for unstable bank conditions.

Stream margin conditions up to 50 feet from the water's edge can be evaluated best on the 1:1584 color photographs. All the conditions identified on the 1:600 scale can also be observed at the 1:1584 scale; however, the detail is not as good. Additional features that can be seen include signs of cattle grazing, roads and trails, and in a broader view, ecological zones such as wooded reaches, meadows, and marshy stretches.

A more comprehensive view of streambanks and surrounding terrain, at distances greater than 50 feet, was obtained on the 1:6000 photographs. Color or panchromatic photographs at this scale would be useful for preparing special-purpose maps and for management planning. For example, a drainage basin map could be prepared by updating an existing map with these photographs. Another possibility is to prepare a photo mosaic from enlarged copies of the 70-mm photographs. The mosaic would serve as an updated map and overlays could be made and used for management planning purposes.

The streambank coverage seemed almost ideal at the 1:1584 scale. Where the stream was near the center of the photograph, we could see 50 feet on either side of the stream. Fifty feet from the bank of a 100-foot-wide stream seemed adequate to assess most of the shadow cover on the stream from nearby trees. However, not all trees could be seen on the photographs, for several reasons. First, if the stream was not in the center of the photograph (because of meandering by the stream or the aircraft) the 50-foot distance was not covered. This problem may be lessened by use of a slower aircraft (90 m/h or less) or a helicopter during the photo run. Also, trees taller than 50 feet and trees on moderate-to-steep slopes, whose shadows extended beyond 50 feet, were not covered by the photography. On the Hat Creek study area, a few steep slopes support trees 100 feet tall, or taller. When such slopes are on the east or west side of the stream, a slightly smaller scale of photography may be needed to fully assess the shadow effects.

Accuracy of Interpretation

From a total of 400 points interpreted on the photographs 95 points were selected at random and checked for accuracy on the ground (*table 2*).

Unfortunately, in such a small sample, not all classes were represented; aquatic vegetation and one bottom type, four streambank cover types, and two streambank types were checked and verified in the field. Aquatic vegetation was correctly identified in all cases where it was visible on the photographs and

Table 2—Accuracy of classification for four trout stream condition classes using conventional photointerpretation techniques: color photographs, 1:1548 scale, taken 1968 and 1969, Hat Creek, California

Stream condition	Points correct	Points incorrect	Total
Aquatic vegetation			
Submergent	6	0	6
Bottom types			
Sand	2	0	2
Subtotal	8	0	8
Bank cover types			
Bare soil	2	1	3
Gravel, rocks, boulders	3	0	3
Grasses, green	37	6	43
Grasses, brown	4	0	4
Subtotal	46	7	53
Bank types			
Low bank, no undercut	13	17	30
High bank, undercut	1	3	4
Subtotal	17	20	34
Total	71	27	95

not obscured by overhanging vegetation, shade, or rough surface water. Sand was correctly identified and was found to be associated with smooth surface water near banks of the stream and sandbars.

In most instances, bank cover classes were as we had identified them on the aerial photographs. One exception was on areas where dead grasses and bare soil were misinterpreted several times on the 1968 photographs. The film had been exposed for water (dark) rather than for streambanks (light), causing a "washed out" or overexposed appearance of the streambank details. Streambank interpretation errors were minor, however, when considered in relation to the amount of stream detail observed on film that had been exposed for water.

Results were often incorrect when bank types were classified by combining interpretation of form and shape with height estimations. Heights were based on photo comparisons with familiar objects. These inaccuracies (*table 2*) may be due in part to the following problems: (1) difficulty in determining how far the rising ground bordering the stream extends upward and to what point it still can be defined as part of the bank, (2) difficulty in determining the top of some irregularly-shaped banks, and (3) difficulty in determining margins of the stream when they are obscured by vegetation such as cattails or other high marsh grasses.

Accuracy of Measurements

Measurements of stream trout habitat parameters

by means of aerial photo measuring devices, aids, and techniques were checked for accuracy.

Bottom types and water depths were measured directly on the photographs. Size of bottom types was measured with a particle-size scaling aid (*fig. 3*). Water depths were measured with parallax devices and microdensitometer techniques.

Particle-size—Accuracy was checked by comparing bottom types found in the ground measurements along each transect (at 1-foot intervals) to the photo-identified bottom type falling closest to the transect types. Stream bottoms with rough-textured appearance, such as rubble, rocks, and gravel, were correctly identified in most instances at the 1:1584 scale. The interpreter had some difficulty in differentiating fine (3- to 6-inch) and coarse (6- to 12-inch) rubble types when using the 1:1584 scale aid. With the larger 1:600 scale aid, the fine and coarse rubble types could be more readily classified.

Water Depth—Water depth was difficult to measure with either a 70-mm parallax bar or a parallax wedge because differential parallax (dp) readings are uncertain. The dp value is directly affected by the ability of the interpreter to locate and measure parallax accurately at the surface and on the bottom of the stream. This was nearly impossible to do. For instance, surface readings could not be taken on clear smooth surface water or in shadow areas. Sometimes, however, we were able to obtain a surface reading near the bank and water interface. Bottom types also affected our ability to make dp readings; that is, it was easier to locate a point on boulders and rubble than on sandy or silty bottoms. No bottom readings were made where the water surface was rough or covered by shadows. Where stream conditions permitted dp readings to be made, we found that depth estimates were within ± 2 feet of the actual value. A factor for diffraction at the air-water interface was not used in the estimate. It generally took less time for an interpreter to make a set of dp readings with a parallax wedge than with the 70-mm parallax bar.

Correlation coefficients were calculated for the relation of actual stream depths to optical film density measured with a microdensitometer (*table 3*). The best correlations were obtained on the normal-color transparencies. Smooth water surface transects (*fig. 9a*), with little or no surface reflections, were more highly correlated than rough surface transects (*fig. 9b*). Thus, predictions of water depths are most reliable when there are the least water surface effects.

The high correlation on transect 2 (CIR) was unexpected because clear bodies of water absorb infrared energy and usually appear dark or black on

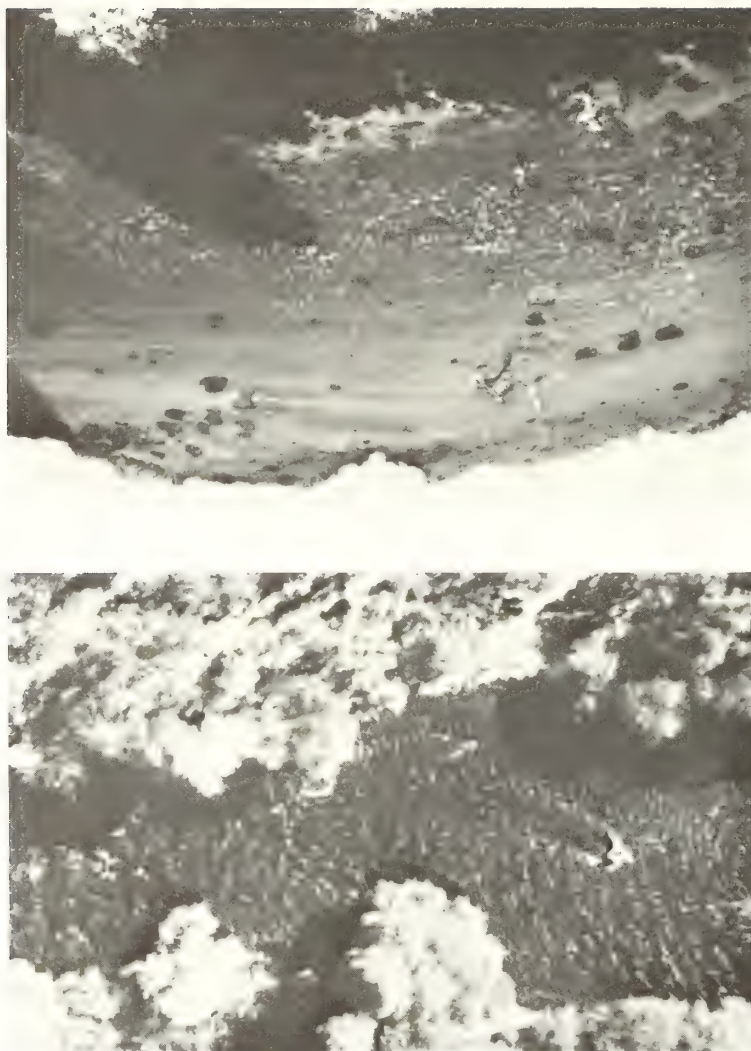


Figure 9—The best correlation between film density and water depth was achieved where the surface of the water was smooth. Here some reflections are seen in midstream on a smooth surface (*top*), but on a rough surface (*bottom*) water surface effects are pronounced.

CIR transparencies. A dark image would result in high uniform density values above 3.00 on a scale of

Table 3—Correlation coefficients for the relation between optical film density and water depth, according to film type and transect (1968 photography, 1:1584 scale, Hat Creek, California)

Transect no. and water surface	Film density/water depth correlation coefficient (%)	
	Color	CIR
1, rough	0.560	0.651
2, smooth	.818	.891
3, smooth	.860	.790
4, rough/smooth	.716	.496
Mean	.764	.735

densities ranging from 0.00 to 4.00. However, our data showed density values ranging from 2.30 to 2.97, and the increases or decreases in values were comparable to changes in water depth (*fig. 10*). We tried the same analysis on the 1969 film density values, but apparently changes in the stream since 1968 resulted in poor data correlations. Further work is required to fully explain the reasons for this poor correlation.

Streambank

A distance-measuring scale was used at the actual scale to make length or width determinations of various stream features. Parallax methods were used to measure heights of banks and vegetation. Measurement of shadow length on the photographs was also

TRANSECT 4 COLOR IR

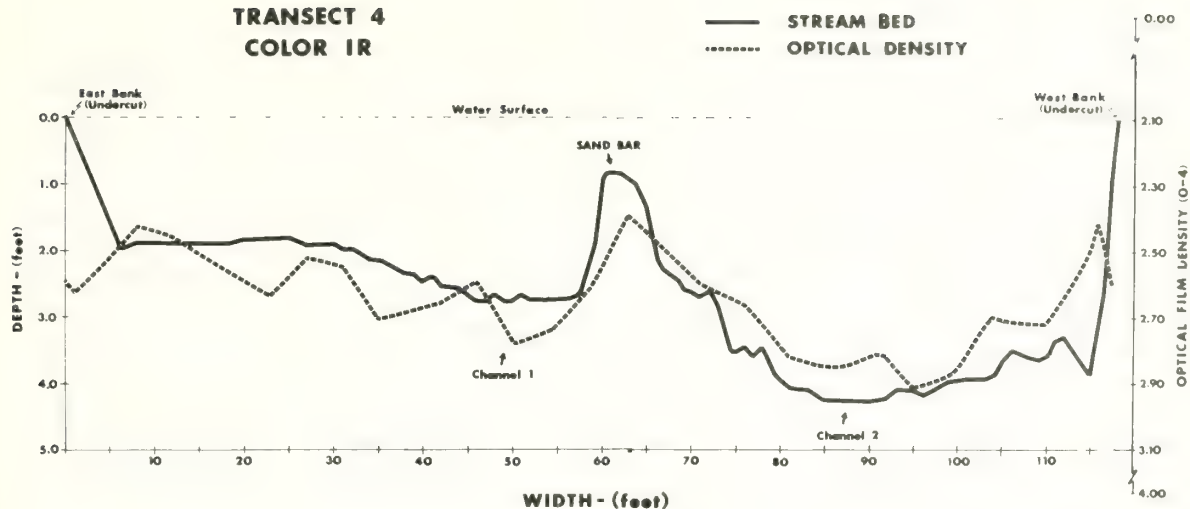


Figure 10—A comparison of optical film density and water depth was made for transect 4 across Hat Creek. Film density was measured on color infrared film at a scale of 1:1584.

used for height determinations. Shade effect tables were developed and used to evaluate shade cover for various times of the day.

Distance—Careful measurements between two points, using the proper scale factor, gave distance accuracies within ± 0.5 ft. Distance could be measured using either the 1:600 or 1:1584 aids on the appropriate photograph.

Bank Heights—Measurement of stream heights on 1:1584-scale photographs with a 70-mm parallax bar worked satisfactorily for banks whose slope extended sharply upward from the edge of the water. Bank heights associated with marsh grasses (2 to 6 inches above water level) were difficult to estimate because the parallax differences were too small to measure accurately. Further work is needed to establish streambank classes that can be measured by parallax

methods, and to develop procedures for measuring length of slope and percent of slope.

Vegetation Heights—Streambank vegetation (bush or tree) heights were measured by three interpreters using the 70-mm parallax bar method and the shadow length method. Using these methods, the vegetation was categorized into one of five height classes (table 4).

When using the parallax bar, the low percentage of correct estimates for smaller vegetation classes (0 to 4 ft, 4 to 15 ft) is partially due to the physical shape of the vegetation. Most of these samples were either bushes or small trees without well-defined tops and shapes as viewed on the photographs, which made it difficult for the interpreter to locate the highest point of a bush or tree for dp measurements. Our data indicate that a ± 0.10 -mm deviation from the true dp

Table 4—Percentage of vegetation samples classified correctly, by height class, measurement method, and interpreter (color and color infrared, 1:1584 scale, taken 1968 and 1969, Hat Creek, California)

Height class (ft)	Number of samples	Interpreter 1		Interpreter 2		Interpreter 3	
		Parallax	Shadow	Parallax	Shadow	Parallax	Shadow
		Percent					
0 to 4	8	44	100	60	100	11	100
4 to 15	9	67	67	67	78	75	100
15 to 50	12	79	92	80	100	93	100
50 to 100	11	82	100	27	82	82	91
100+	4	67	80	0	50	33	67
Mean, all classes		68	88	47	82	59	92

Table 5—Relation of shadow length to height class on 1:1630 (actual scale) photographs taken on October 8, 1968, at 1120 hours PST,¹ Hat Creek, California

Shadow lengths measured on photo (inches)	Vegetation height class (feet)
0.000 to 0.040	5 (0 to 5)
0.041 to 0.080	10 (6 to 10)
0.081 to 0.160	20 (11 to 20)
0.161 to 0.240	30 (21 to 30)
0.241 to 0.320	40 (31 to 40)
0.321 to 0.401	50 (41 to 50)
0.402 to 0.481	60 (51 to 60)
0.482 to 0.561	70 (61 to 70)
0.562 to 0.641	80 (71 to 80)
0.642 to 0.721	90 (81 to 90)
0.722 to 0.801	100 (91 to 100)

¹ Latitude 40°58'20" N; longitude 121°33'11" W.

could affect total heights by 10 feet or less depending on the height of the vegetation.

Measurements of vegetation height using the shadow method were better than those using the parallax methods. The relative ease of measuring shadow lengths with either an inch rule or shadow wedge makes this an appealing method.

One disadvantage of the shadow method is that inaccurate measurements can be made in measuring shadows on moderate-to-steep slopes. Shadow lengths increase or decrease depending on direction of the shadow in relation to slope and position of the

Table 7—Shadow position by hour of day—October 8, 1968, Hat Creek, California

Time (PST)	Shadow azimuth	Time (PST)	Shadow azimuth
0800	297°36'19"	1200	355°45'27"
0900	310°23'12"	1300	23°30'23"
1000	325°46'12"	1400	40°59'42"
1100	344°04'36"	1500	55°12'37"
¹ 1120	350°41'42"	1600	67°08'29"

¹ Time of photography in this study.

vegetation on the slope; that is, a tree located on top of a steep slope casts a longer shadow downslope than a tree located near the bottom of a slope. The problem may be reduced by applying a slope correction factor to the height estimates. These factors were not computed for this study.

Shade Effect—Tables illustrating the effects of shade created by streambank vegetation were developed for the October 8, 1968, photography (*tables 5, 6, and 7*). *Table 5* converts shadow length in inches at 1120 hours on October 8, 1968, to height class in feet. For example, if the shadow of a pine tree is measured and found to be 0.171 inches, it falls in the 0.161 to 0.240 group, and is in the 30-foot height class.

Once the height class is known, the tree's shadow length and position on the stream for any time of day can be determined from *tables 6 and 7*. For example, a tree of height class (30 feet): from *table 6*, at 0800 hours, the shadow length value is 0.608 inches; from *table 7* the position of the tree's shadow on the stream is 297°36'19". With this information it is possible to assess the effects of the tree's shadow on

Table 6—Shadow lengths¹ by hour of day—October 8, 1968, Hat Creek, California

Time (PST)	Shadow length at vegetation height-class (feet) of . . .										
	5	10	20	30	40	50	60	70	80	90	100
	<i>Inches</i>										
0800	0.101	0.203	0.405	0.608	0.810	1.013	1.215	1.414	1.621	1.823	2.026
0900	.065	.131	.262	.393	.523	.654	.785	.916	1.047	1.178	1.309
1000	.049	.098	.196	.294	.392	.490	.587	.685	.783	.881	.979
1100	.041	.083	.165	.247	.330	.412	.495	.577	.660	.742	.825
² 1120	.040	.080	.160	.240	.320	.401	.481	.561	.641	.721	.801
1200	.040	.079	.158	.238	.317	.396	.475	.554	.633	.713	.792
1300	.040	.080	.159	.239	.319	.398	.478	.557	.637	.717	.796
1400	.054	.109	.218	.327	.436	.544	.653	.762	.871	.980	1.089
1500	.077	.154	.307	.461	.614	.768	.921	1.075	1.228	1.382	1.535
1600	.131	.262	.524	.785	1.047	1.309	1.571	1.833	2.094	2.356	2.618

¹ Shadow length values are for the upper limit of each height class.

² Time of photography.

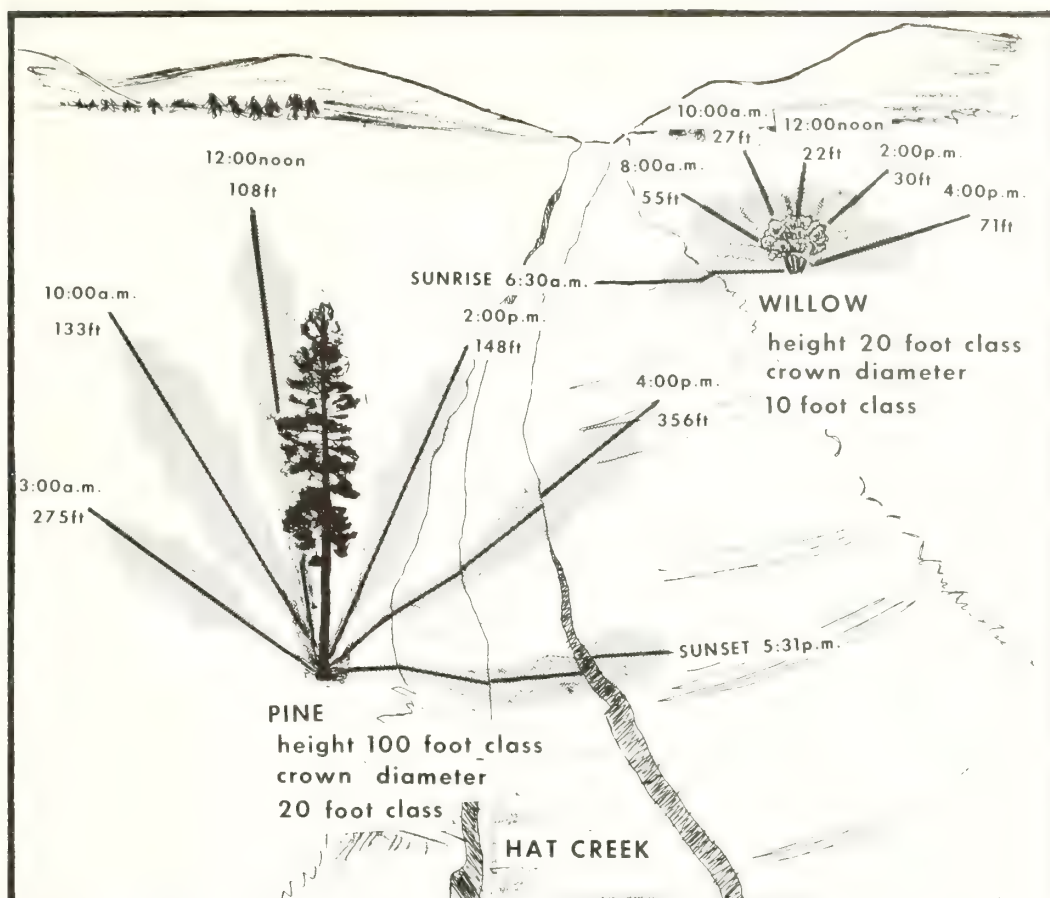


Figure 11—The effects of shade caused by two trees on a portion of Hat Creek—October 8, 1968—are shown diagrammatically.

the stream throughout the day in terms of shade cover for trout. The example (*fig. 11*) shows shadow effects of two trees—one on the east bank and one on the west bank of a north-flowing stream, and how changes in shadow position during the day might affect trout cover. The shadow of the pine tree affects the stream from 2 p.m. until sunset and no shadow affects from the willow tree. In this example, a trout would seek protection from direct sun rays under cover offered by the pine. Since trout have no eyelids and seek shelter in shadowy places to shield their eyes (Schwiebert 1974), this protection is needed more during afternoon hours than early morning hours.

Other measurable factors include size of shaded areas and portions on the stream covered by shadow at various times of the day. The pine with a 60-foot-wide shadow across the stream would provide a larger area for protecting trout from direct sun rays. When coupled with other conditions such as a submerged

log or boulder, the shaded area further enhances good trout habitat. Although cover value of the willow is not as good as that of the pine, the willow would rank higher as a source of plant and insect supply to the stream. The willow may have branches which overhang the water, making it easy for insects and plant litter to fall off into the water. There they become part of the food supply for both trout and aquatic insects.

Habitat Evaluation Cost

The cost of evaluating stream habitats using large-scale color photography varies depending on such factors as (1) the air distance to the stream, (2) the number of streams and distance between streams to be photographed, (3) the length of the stream, (4) the scale of photography, (5) the number of criteria and photo techniques to evaluate habitat, and (6) the number of ground checks required to validate photo

classes and to obtain additional data. Several costs remain relatively constant. These include aircraft flight costs, photographic cost, and photointerpretation costs. Below we have estimated the costs for large-scale photography using two 70-mm cameras for an evaluation of a stream in Shasta County, California. One camera with a 9-inch lens takes normal-color photography at a scale of 1:1600 and a second camera with a 3-inch lens takes 1:4800-scale coverage with panchromatic film. The distance from the aircraft home base is 190 nautical miles. The length of the stream is 10 miles, and because of meanders we have cut it into five sections, each approximately 2 miles long. It is assumed that an interpreter will examine each center photo in a triplet and count or map essential habitat criteria for selecting random ground-check points. The cost of ground checks, a very essential part of habitat evaluation, is not included in our cost estimates. Ground check costs vary widely depending on the sample intensity and the amount of details required.

Aircraft flight costs:	Cost ^a
Aircraft cost (5h, at \$105/hr) ^b	\$ 525.00
Crew cost (8h, pilot & photographer)	128.00
Subtotal	653.00
Photographic costs:	
Film—color, one 100-ft roll @ \$50.00	50.00
pan, 1/3 of 100-ft roll @ \$15.00	5.00
Film processing and printing	20.00
3 man-days	150.00
Mosaic construction (1 man-day)	40.00
Interpretation (color) 150 triplets (transects) @ 6 per day = 25 man-days	1,100.00
Materials	100.00
Subtotal	\$1,465.00
Total cost of photo evaluation	\$2,118.00

^a Costs to the Government without profit margin.

^b Aero Commander, twin engine; time includes cross-country time from the San Francisco Bay Area.

CONCLUSIONS

Aerial photography described in this study can be a valuable tool for evaluating stream trout habitat. Most characteristics of trout streams are visible and are described directly on the photographs. Some conditions such as average size of stream bottom aggregates, depth of water, streambank heights, and heights of streambank vegetation are estimated using special measuring aids. Degree of shade on the stream can be evaluated using a technique that includes measurement of vegetation shadow lengths and vegetation positions in relation to the stream and the use of solar position diagrams or solar formulas. Habitats supporting trout stream insect production can potentially be evaluated using the photographs as a base from which to sample and collect this biological data.

The best overall scale and film for evaluating streambank conditions is normal color at 1:1584 scale. Exceptions to this are areas where low grassy areas with undercut banks occur and where healthy aquatic vegetation is found—here color infrared was the better film. Also, reflections from rough surface water were easier to see on CIR film.

The largest scale (1:600) photographs were better for detailed descriptions of stream conditions and are preferred by fishery biologists. Complete coverage of the stream width is possible at this scale when stream width is less than 100 ft. Color infrared at this scale worked well for assessing aquatic vegetations, whereas color was best for bottom types.

APPENDIX

A: Helpful Formulas

Most of the formulas used in this study may be found in a photointerpretation textbook or in an ephemeris. Because formulas vary in details, however, those we used are given here. They were selected for ease in computation with a tabletop calculator.

Parallax: Used for finding water depths using parallax measuring devices.

$$D_w = \frac{(fl \times dp) \times \text{scale}}{(p \times 25.4) + dp}$$

in which

- D_w = water depth
- fl = the camera lens focal length in feet (in this case 0.5 feet)
- dp = parallax difference between the water surface and the stream bottom (mm)
- Scale = the photo scale factor (denominator of the representative fraction)
- p = air base measurement (inches) (distance between principal point and conjugate point for each stereo pair)
- 25.4 = conversion factor for inches to millimeters

Solar Altitude: Used in formulas for finding shadow azimuth and in formulas to convert shadow length to tree height.

$$\sin x (\text{solar altitude}) = \cos a \cos b \cos c \pm \sin a \sin b$$

In which

- a = latitude of photo (obtained from topographic map of area photographed)

- b = solar declination for the date of photography (obtained from a solar ephemeris for particular year required)
- c = hour angle or difference in longitude of sun at actual time of photography (calculated for time of day at which the air photo was taken).

An example for obtaining the hour angle is found in the textbook *Aerial Photographs in Forestry* (Spurr 1948, p. 230).

Solar Azimuth: Used for finding shadow direction.

$$\sin y = \frac{(-\cos b) (\sin c)}{(\cos x)}$$

In which

- $\sin y$ = sun's azimuth
- $\cos b$ = solar declination for the date of photography
- $\sin c$ = hour angle at actual time of photography
- $\cos x$ = solar altitude

Shadow length to height conversion: Used to obtain streambank vegetation heights.

$$H = (L) (\text{RF factor}) (\tan x)$$

In which

- H = height of tree in feet
- L = measured shadow length on photograph to the nearest 0.01 or 0.001 inch
- RF factor = scale for photograph on which shadow measurements are made in feet (denominator of the representative fraction)
- $\tan x$ = tan value for the solar altitude x .

B: Procedures for Determining Degree of Shade on a Stream

A. Complete the following steps once for each date and time of photography.

1. Find the values for altitude and azimuth of the sun. One convenient way is to use computer-generated solar position diagrams. The diagrams are for each 2° of latitude from 0°–90° and show altitude and azimuth of the sun when time, date, and latitude of photography are known (Clark 1971).

Another way requires solving equations for solar altitude and azimuth (See Appendix A). Even though the calculations are lengthy, the values obtained are more accurate than those taken from the diagrams; the equations are based on apparent positions of the sun in the sky, whereas the diagrams use average position of the sun for each 2° of latitude.

2. Determine the shadow position. Using the solar azimuth equation, the solar azimuth at 1120 hours on October 8, 1968 (the time and date of our photography) at a latitude of 40°58' is -9°18'. Shadow position is the back azimuth ($\pm 180^\circ$) degree reading of this value or 350°42'.

3. Determine a true north line. True north is found on a single photograph by placing the center of an azimuth circle (0° to 360°) or protractor on the center of a tree crown with a well-defined shadow. Align the shadow with the 350°42' mark on the protractor. Without moving the protractor, locate 0° and mark this point on the photograph. A line connecting this point and the center of the tree crown is a true north line.

B. Complete the following steps to determine which bushes or trees affect the stream. Measurements are made on photo stereo triplets.

1. Determine the position of a bush or tree in relation to the stream. Once the true north line is established, the position of any bush or tree in relation to the stream is found by measuring with a protractor on a single photograph.

2. Determine the distance of each bush or tree from the stream. The distance is measured perpendicular to a tangent at the nearest point on the streambank using the appropriate scale factor on the distance measuring scale.

3. Determine the height of a bush or tree. Heights can be measured in a number of ways using parallax devices (Weber 1965; Wert and Myhre 1967), or shadow length (Spurr 1948). We tried two methods for measuring vegetation heights:

- (1) A 70-mm parallax bar which measures differential parallax (dp) in units of 0.001-mm on stereophotos. The parallax principles used to estimate depths of water also apply to vegetation height measurements, with dp measured at the top and bottom of a tree.

- (2) A ruler or shadow wedge which measures shadow lengths in increments of 0.01 inch or 0.001 inch on a single photo. The solar altitude value and the measured length of a shadow are used in the shadow height equation (See Appendix A). A height-class table based on measured length of shadow can be prepared when many heights are needed. *Table 5* (see text) is an example for the October 1968 photography.

C. Determine shadow azimuth and shadow length for a range of times other than the time of the photography. This step is made simplest by preparing tables, similar to *tables 6 and 7* in text, for assessment of shadow effects throughout the day. With additional photography for each of the four seasons, these tables may be expanded over a year's time.

D. Complete the following steps on those bushes and trees which affect the stream.

1. Determine whether a bush or tree is evergreen or deciduous. This is done by interpretation of crown shape, color, and branching characteristics.

2. Measure the crown diameter of a bush or tree. Use the distance-measuring scale or a crown diameter wedge.

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Greentree, Wallace J., and Robert C. Aldrich

1976. **Evaluating stream trout habitat on large-scale aerial color photographs.** USDA Forest Serv. Res. Paper PSW-123, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Large-scale aerial color photographs were used to evaluate trout habitat by studying stream and streambank conditions. Ninety-two percent of these conditions could be identified correctly on the color photographs. Color photographs taken 1 year apart showed that rehabilitation efforts resulted in stream vegetation changes. Water depth was correlated with film density: 76.4 percent on normal color film and 73.5 percent on infrared film. Shadow-length measurements of streambank vegetation height were 86 percent accurate. A technique to measure the degree of shade created by streambank vegetation is described. The cost of large-scale color evaluation of trout habitat was estimated to be from \$200 to \$250 per mile of stream.

Oxford: 587.6:156.7-147.

Retrieval Terms: trout habitat; photointerpretation; habitat evaluation.

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Low-volume and Slow-burning Vegetation for Planting in Clearings in California Chaparral

Eamonn C. Nord

Lisle R. Green



CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Species Performance Testing Methods	4
Useful Grasses	7
Perennial Grasses	7
Annual Grasses	9
Shrubs	9
Low-growing Shrubs	16
Semiprostrate Shrubs	27
Taller Shrubs	32
Appendix	36
A. The Vegetation Around Structures	36
B. Index of Common and Scientific Names of Species	38
Literature Cited	39

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SUMMARY

Nord, Eamor C., and Lisle R. Green

1977. **Low-volume and slow-burning vegetation for planting on clearings in California chaparral.** USDA Forest Serv. Res. Paper PSW-124, 41 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 432.17-018

Retrieval Terms: fire-resistant plants; fuel modification; fuelbreaks; fire hazard reduction; vegetation establishment.

One means of reducing size and damage from wildfires in California has been fuel modification—replacement of hazardous fuels, primarily chaparral, with vegetation of lower fuel volume or flammability, or both. Unless suitable plants are established, when chaparral is cleared, flammable annual grasses and forbs dominate the site.

A search for suitable plants has been carried out intermittently during the past 35 years. In 1963, research was intensified at the Pacific Southwest Forest and Range Experiment Station. Results of this work show there are several shrubs, mostly low-growing species, and a few perennial grasses that can be established and grown satisfactorily under wildland conditions. Subsidiary studies carried out concurrent with test and field plantings at several locations showed that shrubs with high mineral (or ash) content held and retained considerably higher fuel moisture throughout the year, and thus were not as flammable as most chaparral and other species tested which had low mineral or ash content.

Some 50 or more shrub species or taxa and numerous grasses were tested. About 20 shrubs and an equal number of grasses showed promise for planting on fuelbreaks or other brush-cleared areas. The list included 11 low-growing, 2 semiprostrate, and 3 upright shrubs. Within each of these categories were a

few species that had a rather wide range of soil and elevational adaptability. Creeping sage fit more requirements than other shrub species tested for planting on fuelbreak sites. This plant, only a few inches high, provided a relatively dense cover that tended to inhibit growth of most other plants and proved it could slow down the rate of fire spread, especially within annual vegetation. The lavendercottons, Descanso rockrose, and some saltbushes were likewise adapted to many different sites. Several other shrubs and some grasses were suitable but only for a limited set of conditions. Creeping sage and a few saltbush species were successfully established by drill seedings upon properly prepared seedbeds along fuelbreaks.

In this report, characteristics of the individual species and their usefulness for planting are described; and directions are given for collecting or treating seed to improve germination, propagating plants from cuttings, and establishing these plants on wildland sites. The role of perennial grasses and trees, particularly to reduce fire hazards from brushlands near urban situations, is discussed. A number of the species described could serve not only to reduce fire hazards but for soil stabilization and improving wildlife habitat, and are attractive for landscape use near homes as well as for planting over more extensive areas.

An average of more than 11,000 wildfires a year burned in California during the 5 years ending in 1975.¹ Less than 2 percent of these fire starts became the extensive and damaging fires called conflagrations, yet in 1970 about half a million acres were blackened. There has been at least one fire exceeding 10,000 acres in extent in every year but one since 1960.

These periodic large wildfires cause staggering losses in structures burned, watershed blackened, postfire erosion, and floods.

One means for reducing spread and damages from wildfire is to replace hazardous fuels with vegetation that has low fuel volume or low flammability, or both. Such fuel modification is needed especially on fuelbreaks, along roads, near structures, and under powerlines. Areas that do not burn over rapidly, nor with great heat output, can provide firefighters safe access into brushfields, and a place to begin fire suppression action. Protection of structures is also easier if surrounding fuel is modified.

Herbaceous annual plants, especially grasses, usually dominate following clearing of chaparral. They are very flammable when dry, and fire spreads rapidly in such fuel. To replace the annuals, plants are needed that will grow on wildland sites with little or no maintenance, and burn less readily than the annuals, with less heat output than the chaparral. Extensive efforts have been made to identify such plants. Acceptable vegetation for planting on fuelbreak and related wildland sites will possess some of the following characteristics:

1. *Low volume*—Because heat output from burning fuel tends to be proportional to the quantity of fuel—the fuel volume—low-volume plants are preferred on fuelbreaks or other control lines. Some relatively tall plants can be considered in this group, but these generally have a high mineral content which, with associated high moisture content, tends to make the plants slow to ignite and burn.

2. *Low growth form*—Low prostrate shrubs that creep along and cover the ground are most desirable.

Some spreading grasses and forbs are also useful, although they are more apt to become dry and flammable during the summer.

3. *Wide adaptability*—Plants of interest must be adaptable to dry chaparral sites, and preferably to a moderately broad range of elevations, exposures, temperatures, and soils if they are to be useful.

4. *Reproducibility*—Species or varieties which reproduce vegetatively by adventitious roots, rhizomes, or stem layering, as well as by seed, have an advantage under dryland conditions. These characteristics allow plants to establish themselves or spread when seed will not germinate and grow. It gives them added power to recuperate after injury, as by drought or grazing.

5. *Widespreading, deep root systems*—Plants with much branched, deep, and fast-growing root systems are preferred because they make best use of available nutrients and soil moisture. They are less susceptible to frost heaving than plants with a deep tap root.

6. *Relatively low flammability*—Plants that retain high moisture content into the summer ignite and burn less readily than plants of lower fuel moisture. High summer moisture content is frequently correlated with high mineral or ash content. Any plant called “greasewood,” such as chamise and other plants that contain large amounts of tars, resins, or other flammable, volatile products, burns readily and is undesirable.

7. *Palatability to animals*—Palatable plants such as the saltbushes and ceanothus are subject to destruction during the establishment stage, or in sparse stands. Grazing or browsing of mature plants is desirable, however, because it reduces accumulation of dead and live fuel.

The search for plants that do not burn as readily nor supply as great fuel volume as native fuels began in 1928, when the Forest Service started test plantings of ice plant (*Mesembryanthemum* spp.), woody spurges (*Euphorbia* spp.), other succulents, and some saltbushes (*Atriplex* spp.) in southern California forest and nursery tests. These plantings succumbed to browsing, summer drought, or low winter temperatures (Ilch 1952). The effort diminished during the late 1930's and 1940's, but during the 1950's, personnel at the Los Angeles County Arboretum and

¹California Department of Conservation, Division of Forestry. 1976. *California Wildfire Summary—1975*. 1 p.

Angeles National Forest started looking for slow-burning plants that would grow under southern California watershed conditions (Green 1965). The Pacific Southwest Forest and Range Experiment Station assigned a scientist, the senior author, to work full time on low-growing shrub research in 1963. The California Department of Forestry and the Los Angeles County Fire Department were interested and have participated in much of the work. Joint studies are in progress.

This paper summarizes findings of the Pacific Southwest Forest and Range Experiment Station, and some experience of cooperators. The brief section on

grasses that may be planted on fuelbreak sites consists of recommendations based on research that antedates or, for a few species, parallels the shrub studies. The shrub work has not been reported previously.

The reports of test results consist of tables showing relative performance of species, followed by descriptions of those species found most suitable. The descriptions cover plant origins, general characteristics, and other details pertinent to establishment of the species in fuel modification projects. Selection and management of vegetation to minimize fire hazard around homes is covered briefly in the Appendix.

SPECIES PERFORMANCE TESTING METHODS

Before 1965, species tested for chaparral areas were primarily grasses and forbs intended to provide herbage for domestic livestock. Grasses have been test planted on burned or mechanically cleared chaparral areas for more than 35 years (Jones and Love 1945, Bentley and Talbot 1949). The University of California, the California Agricultural Extension Service, the Forest Service (Pacific Southwest Forest and Range Experiment Station and California Region), and the Agricultural Research Service have tested promising grass and forb species throughout the State, frequently in joint studies (Bentley and others 1956). The Soil Conservation Service tested grasses and forbs for wildland plantings, and maintained facilities to produce seed for testing of promising strains or species. Edmunson and Cornelius (1961) and Green and others (1963) reported on tests aimed particularly at developing recommendations for fuelbreak planting in southern California. For grasses recommended as a result of these tests, cultural methods and site requirements are known, and seed is commercially available.

Since 1965, our program has aimed at developing low-volume shrubs for fuelbreak planting, although some attention has been given to tall-growing shrubs that may burn less readily than most chaparral species. The need is for shrubs that grow no taller than 1 foot (0.3 m), that are prostrate in growth habit, and that spread outward with dense enough foliage to suppress annuals. Suitable plant materials have been selected from domestic and foreign sources, and methods have been developed for propagating plants from seed or vegetative material. Greenhouse and field plot tests have been conducted, and some species are currently under test in large plot

field plantings. Still to come is the development of seed supplies of most shrubs, and management guidelines for shrub stands established on wildland sites.

Initial field tests were made from 1964 to 1973 at 11 sites (*table 1*), as suitable shrubs came to our attention. The primary test sites were on or near the North Mountain Experimental Area, near Banning in Riverside County, at 3600 (1097 m) and 5000 (1524 m) feet elevation. Others were elsewhere in Riverside County and in Los Angeles and San Diego Counties.

At all sites, chaparral vegetation was cleared and the ground prepared for planting by disking or rototilling, which reduced competition from annuals. Rooted transplants grown in asphalt or milkboard pots, generally 2 to 3 inches (5 to 7.6 cm) square by 8 to 12 inches (20 to 30 cm) deep, were used in initial tests. In only a few instances, and then only for 2 to 3 weeks after planting, was there any supplemental watering of the plants. Some of the plantings at the Nixon site in the North Mountain Experimental Area were protected from both grazing animals and rabbits by an enclosure fence. No protection from animals was provided for other plantings except that a few plants were initially protected by means of wire domes or cages, primarily against rabbit clipping, at a few locations.

More than 40 woody plant species and varieties were installed at one or more of the study sites during the past 10 years. Some were planted at several locations to determine their range of adaptability; plantings were installed in different years at the same site to compare annual variability; and species were either seeded or transplanted by various techniques to determine feasible means of establishment.

Table 1—Location and general characteristics of sites in southern California where low-volume/slow-burning shrubs were tested between 1964 and 1973

Site	Location and management unit	Elevation	Annual precipitation	Soil
		Feet (m)	Inches (cm)	
Primary test sites:				
Nixon	North Mountain Experimental Area (Bur. Land Manage.), Riverside Co.	3600 (1097)	21 to 23 (53 to 58)	Very sandy loam to loamy sand; pH 5.8 to 7.0.
Vista Grande	San Bernardino National Forest, Riverside Co.	5000 (1524)	30 to 32 (76 to 81)	Deep, loamy sand; pH 5.3 to 6.0.
Other test sites:				
Wolfskill	North Mountain Experimental Area (Bur. Land Manage.), Riverside Co.	2600 (792)	15 to 18 (38 to 46)	Moderately deep, fine sandy loam; pH 5.6 to 7.3.
Mill Creek Summit	Angeles National Forest, Los Angeles Co.	5200 (1585)	28 to 30 (71 to 76)	Moderately deep sandy loam; pH 6.2 to 6.8.
Upper Big Tujunga (Lynx Gulch)	do.	3400 (1036)	15 to 18 (38 to 46)	Very deep, loamy sand to sandy loam; pH 6.4 to 7.0.
Mill Canyon	do.	3000 (914)	18 to 20 (46 to 51)	Moderately deep, loam to heavy sandy loam; pH 6.5 to 7.0.
Alder Gulch	do.	4500 (1372)	20 to 24 (51 to 61)	Moderately deep, gravelly sandy loam; pH 6.2 to 7.0.
Sierra Saddle	Angeles National Forest, Los Angeles Co.	2500 (762)	15 to 18 (38 to 46)	[Data not available.]
Malibu Nursery	Los Angeles Co., Forestry Division, Los Angeles Co.	Below 2000 (610)	15 to 25 (38 to 64)	Deep, sandy clay loam; pH 7.0 to 7.6.
Jamul Ranch	Daley Ranch, San Diego Co.	1000 (305)	14 to 18 (36 to 46)	Deep sandy loam to sandy clay loam; pH 6.2 to 6.6.
Manzanita	Manzanita Indian Reservation, San Diego Co.	4000 (1219)	11 to 23 (28 to 58)	Moderately deep, loamy coarse sand; pH 6.0 to 7.2.

The number of plants used depended to some extent upon the supply available. At least 10 and usually 50 or more plants were installed at 1- to 4-foot (0.3- to 1.2-m) intervals along rows 3 feet (0.9 m) apart at each site (*fig. 1*).

The evaluation of relative performance of species tested took into account emergence and establishment of seedlings, plant survival, growth habit—especially by vegetative means (stem layering or root sprouting)—rate of growth, susceptibility to animal damage—especially by rabbits—and other plant responses.

Several species were evaluated in the Riverside nursery, and in limited numbers at a few other places, then were dropped from further consideration. These species are included in the tabulation of results with other plants found unsatisfactory.

Records of plant survival and growth were taken two or three times during the first year, and annually thereafter. Representative plants of a few species were excavated to determine the nature and extent of their rooting systems during the first year or two after establishment on field sites (*fig. 2*).

Concurrent studies or tests were conducted to determine means of improving germination (Nord and others 1971), methods for propagating plants from cuttings (Nord and Goodin 1970), and direct seedings to develop better methods for producing and establishing shrub plants. This included studies on time and depth of saltbush seedings (Nord and others 1971), and current work still in progress on prostrate ceanothus or squawcarpet (*Ceanothus prostratus* Benth.) and creeping sage (*Salvia sonomensis* Greene.).



Figure 1—Nixon enclosure, North Mountain Experimental Area, Riverside County, California. Here, at 3500 feet elevation in the San Jacinto Mountain range, low-profile or slow-burning shrubs are tested for adaptability.

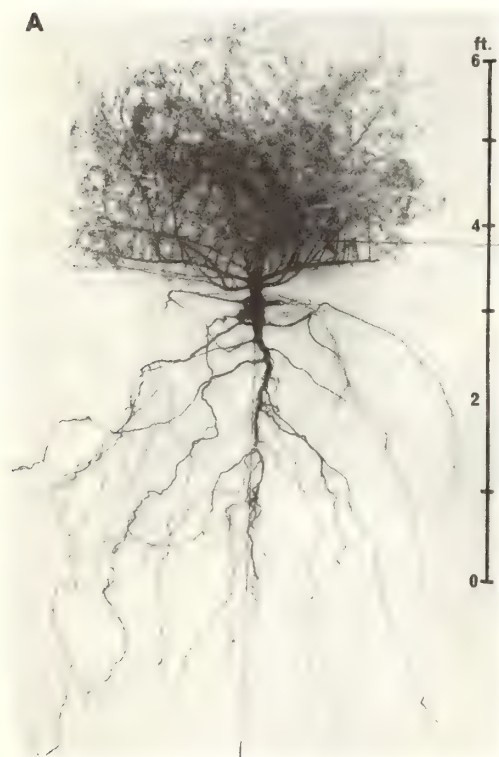


Figure 2—Representative low-profile or slow-burning shrubs were excavated to determine the nature and extent of root systems during the first year or two after establishment: *A*, 2-year-old creeping sage grown from fresh stem cutting; *B*, 1-year-old fourwing saltbush grown from seed planted on the Nixon test plot, North Mountain Experimental Area, Riverside County, California.

USEFUL GRASSES

Perennial Grasses

Perennial grasses have been recommended ground cover for fuelbreak sites, where they are adapted, for many years (fig. 3). There are several reasons:

- Viable seed of most recommended species is commercially available, and methods of establishment are well known. This is a tremendous advantage of perennial grasses over many shrub species whose seed must be hand collected, treated to break dormancy, and planted when we do not know much about the planting conditions needed, or when they must be reproduced from vegetative cuttings.
- They usually have deep, spreading root systems that enable them to draw on moisture not available to most annuals, and they stay green later into the summer. This makes them less flammable than annuals during part of the summer, and in the fall when they green up again.
- Successfully established in near solid stands, they provide a barrier that usually prevents reinvasion by woody vegetation.
- Once established, they provide herbage for grazing animals.



Figure 3—Perennial grasses, where adapted, make excellent fuelbreak ground cover. Seed is available, excellent forage is provided, and a solid grass cover provides a barrier to reinvasion of brush.



Figure 4—Intermediate and pubescent wheatgrasses (left) spread from underground stems (rhizomes). Bunchgrasses, such as tall wheatgrass or crested wheatgrass (right), depend predominantly on seed, an undependable method of reproduction for perennial grasses on dry or weedy sites.

There are limitations to use of perennial grasses, however. One is that in the chaparral zone they need a soil that can store 3 inches (7.6 cm) or more of available moisture in the surface 3 feet (0.9 m). Fine sandy loam, loam, or clay loam soils more than 2 feet (0.6 m) deep meet this requirement. Annual rainfall of at least 15 inches (38 cm) is needed on fine-textured soils, and 20 inches (50 cm) on sandy loams.

Another limitation is that perennial grasses need to be grazed once they are established. This prevents undesirable fuel accumulation, and it encourages “stooling out,” resulting in better ground cover and reduced height growth. Attracting livestock in sufficient numbers to fuelbreak situations has not always been possible. Contracting and paying for grazing by bands of sheep may be a solution.

Several perennial grasses are useful as low-volume ground cover:

Two wheatgrasses, intermediate (*Agropyron intermedium* [Host] Beauv.) and pubescent (*A. trichophorum* [Link] Richt.), are highly recommended. Both are introductions from eastern Europe or central Asia. Both are palatable to livestock. They become established readily from seed, and spread to form a loose sod from short rhizomes (fig. 4). Under dryland conditions, seed stalks grow 1 to 1½ feet (30 to 45 cm) tall, but on good site and with adequate moisture, they may be twice as tall. Pubescent wheat-

grass is somewhat more drought resistant than intermediate, and is recommended in the California brushfields above 2000 feet (610 m) elevation wherever rainfall is 15 inches (38 cm) or more (table 2). Intermediate wheatgrass needs a little more moisture—20 inches (50 cm) or more—and does best at elevations above 3000 feet (914 m) in southern California.

Tall wheatgrass (*A. elongatum* [Host] Beauv.) grows very well in the chaparral belt, but is not as well suited to fuelbreak situations as pubescent and intermediate wheatgrasses. It does not spread from the original bunches, grows taller and coarser, and is less palatable than pubescent or intermediate wheatgrass, and produces more fuel.

Hardinggrass (*Phalaris tuberosa* L. var. *stenoptera* [Hack.] Hitchc.) is a long-lived grass, planted more widely than any other perennial on low-elevation rangeland in California. It does best with 15 to 25 inches (38 to 64 cm) of precipitation, between 500 and 3500 feet (150 and 1067 m) elevation. On good sites, it produces an abundance of palatable herbage that is closely cropped by livestock. After maturing, stems frequently remain green near the base.

Several other perennial grasses should not be the dominant part of a planting mixture, but may be useful. Smilgrass (*Oryzopsis miliacea* [L.] Benth.) is a palatable, long-lived grass adapted to 16 inches (40 cm) or more rainfall, and elevations to 3000 feet (914 m). It could be a valuable plant for fuelbreak use because the stems stay green into the summer, except that seeding success has been poor. This is because the extremely small seed—about 880,000 per pound or 1940 per gram—can easily be planted too deep (below 1/4 inch, 6 mm); the tiny seedlings often do not emerge through crusted soil, do not survive drought, or do not compete well with weeds; and the seed has a hard outer coat. Germination can be improved by soaking seed for 20 to 40 minutes in 70 percent sulfuric acid (Koller and Negbi 1959), or for 1 hour in household bleach (Love and others 1952). The ash formed in burning of woody fuels has a similar effect, and good stands have developed on recent brush burns. Smilgrass is a good candidate to include in any perennial grass mixture at lower elevations.

Perennial veldtgrass (*Ehrharta calycina* Sm.) is a

Table 2—Grass species recommended for fuelbreak sites in California¹

Species	Elevation		Seeding zone	Rainfall		Recommended sowing rate	
	Feet	Meters		Inches	Cm	Lb/acre	Kg/ha
Hardinggrass	To 4000	To 1220	Coastal and inland	15 to 30	38 to 76	2	2.24
Smilgrass	To 4000	To 1220	Coastal and inland	15 to 30	38 to 76	1	1.12
Veldtgrass	To 4000	To 1220	Coastal	15 to 25	38 to 64	2	2.24
	To 4000	To 1220	Inland southern	20 to 30	51 to 76	1	1.12
Pubescent wheatgrass	To 4000	To 1220	Coastal and inland	15 to 30	38 to 76	2	2.24
	3500 to 6500	1067 to 1980	Inland mountain	15 to 25	38 to 64	4	4.48
	3500 to 6500	1067 to 1980	Inland mountain	25 to 45	64 to 114	2	2.24
	3000 to 8000	914 to 2438	Desert side, mountain	15 to 25	38 to 64	2	2.24
Intermediate wheatgrass	To 4000	To 1220	Coastal	20 to 30	51 to 76	1	1.12
	3500 to 6500	1067 to 1980	Inland mountain	15 to 25	38 to 64	2	2.24
	3500 to 6500	1067 to 1980	Inland mountain	25 to 45	64 to 114	3	3.36
	3000 to 8000	914 to 2438	Desert side, mountain	15 to 25	38 to 64	2	2.24
Goar's tall fescue	To 4000	To 1220	Coastal	20 to 30	51 to 76	1	1.12
	3500 to 6500	1067 to 1980	Inland mountain	25 to 45	64 to 114	1	1.12
Sherman big bluegrass	To 4000	To 1220	Inland central	20 to 30	51 to 76	1	1.12
	3500 to 6500	1067 to 1980	Inland mountain	15 to 45	38 to 114	1	1.12
	3000 to 8000	914 to 2438	Desert side, mountain	15 to 25	38 to 64	1	1.12
Orchardgrass	3500 to 6500	1067 to 1980	Mountain	25 to 45	64 to 114	1	1.12
Crested wheatgrass	3000 to 8000	914 to 2438	Desert side, mountain	15 to 25	38 to 64	2	2.24
Blando brome (annual)	To 4000	To 1220	Coastal	15 to 30	38 to 76	¼ to ½	0.28 to 0.56
			Inland	20 to 30	51 to 76	¼ to ½	0.28 to 0.56

¹ Adapted from Green and others 1963, and Bentley 1967.

short-lived perennial that reseeds itself on sandy or sandy loam soils in the central and south coast regions of California. It also did well in the San Gabriel Mountains above Glendora, California at 4000 feet (1220 m) elevation.

Sherman big bluegrass (*Poa ampla* Merr.) is native to northern California, although the Sherman strain was collected in eastern Oregon. It is a short bunchgrass whose greatest usefulness is above 3500 feet (1067 m) elevation.

Less thoroughly tested are sandhill grass and buffelgrass. Sandhill grass (*Brachiaria ciliatissima* [Buckl.] Chase), is native to sandy ground in the Texas-Arkansas gulf coast area. It produces seed, but also long leafy stolons that root at the nodes. It is moderately frost tolerant; sandhill grass and creeping sage were the only two survivors of nine species planted on a roadside cut above Pasadena, California at 2500 feet (760 m) elevation. Plantings near Jamul, 20 miles (32 km) east of San Diego, were doing well in June 1973. Seed is not available commercially, but can be readily collected.

Buffelgrass (*Pennisetum ciliare* [L.] Link) was introduced from south Africa into our southern states, and from there into the warm western states. It has grown better than most other species on infertile sandy soils. It is a heavy seeder; the seed is fuzzy and difficult to harvest, but commercially available. A seeding on the Jamul Ranch in San Diego County in 1972 appeared promising. A variety known as "Higgins" buffelgrass grows from rhizomes; it has also been planted with some success in San Diego County.

Fountaingrass (*P. setaceum* [Forsk.] Chiov.), also from Africa and originally used in this country for ornamental plantings, has been successfully established and good stands have developed from seedings on disturbed sites, especially along road cut or fill slopes in Los Angeles, Orange, Riverside, and San Diego Counties at elevations below about 1500 feet

(460 m). This grass is somewhat taller but in most other respects is quite similar in appearance to buffelgrass. Seed is also commercially available.

Annual Grasses

When woody fuels are cleared from wildland sites by wild or prescribed fire or with mechanical tools, a replacement cover of herbaceous annuals develops rapidly. This comes from viable seed present before burning or clearing, and from seed carried or blown into the cleared area. It consists of mostly nongrassy plants -forbs- following hot fire and, after the first year, annual grasses as well. Sprouts from woody plant crowns and brush seedlings also appear. Annual ryegrass (*Lolium multiflorum* Lam.) or blando brome (*Bromus mollis* L.) may be introduced artificially during the first year.

The herbaceous cover reverts to brushland in a few years, unless woody vegetation is controlled. If brush is controlled, the annual cover is usually an ecologically unstable mixture of annual grasses and forbs that is soon invaded by biennial or perennial herbs and shrubs such as *Penstemon*, deerweed (*Lotus scoparius* [Nutt. in T. & G.] Ottley), and California buckwheat (*Eriogonum fasciculatum* Benth.).

Such a plant mixture has a reputation among firefighters of rapid fire spread and intense heat when it burns during the summer and fall months. Nevertheless, it does have a low flammable fuel volume -1/2 to 3 tons per acre (0.45 to 2.7 M.T.)—as opposed to 5 to 40 tons (4.5 to 36.3 M.T.) found in brushfields or conifer forests.

On sites with shallow soils, low rainfall, or other undesirable characteristics, the cover of annual grasses and forbs may be the best low-volume cover the site will support. To date, planting improved or specialized vegetation has not been successful under these conditions.

SHRUBS

About one-fourth of the species and varieties tested, including two to four each of low-volume, semiprostrate, and taller shrub classes, were promising (tables 3, 4). These plants could all be readily established—some by direct seeding as well as by transplanting; survival was uniformly high, usually 50 percent or higher; and growth was satisfactory over a relatively wide range of conditions commonly present in brushland areas. Nearly half of the species made at least fair growth, indicating they would be useful on

some brushland sites. Twenty-two species were unsatisfactory for one or more reasons (table 5).

None of the species tested grew throughout the range of chaparral site conditions, but creeping sage comes as close as any. The promising low-growing group included the two santolinas or lavendercottons (*Santolina chamaecyparissus* L. and *S. virens*). These were established from rooted transplants. Among the semiprostrate and upstanding shrubs that had good performance were rockrose (*Cistus crispus* L., *C.*

Table 3—Relative performance of low-growing¹ shrub species for plantings to reduce fire hazards in southern California brushland clearings

Species and native source	Elevation range of adaptability			How established			Growth rate			Remarks
	<2000 ft (<610 m)	2000 to 4000 ft	>4000 ft (>1220 m)	Direct seeding	Stem cuttings	Rooted transplant	Fast	Med.	Slow	
<u>Good performance</u>										
<i>Salvia sonomensis</i> Creeping or Sonoma sage, California	X	X	X	X	X	X	X			Good in most respects. Stem layers.
<i>Santolina chamaecyparissus</i> ² Gray santolina or gray lavendercotton, Mediterranean region	X	X	X	O	O	X	X			Lower in height and denser than <i>S. virens</i> ; stem layers.
<i>S. virens</i> ² Green santolina or green lavendercotton, Mediterranean region	X	X	X	O	O	X	X			Has fine, porous foliage; quite flammable.
<u>Fair performance</u>										
<i>Artemisia caucasica</i> ² Caucasian artemisia, USSR	X	X	X	O		X		X		Attractive, aromatic; stem layers; seed is sterile.
<i>Atriplex cuneata</i> Castlevalley saltbush, central Utah	O	X	X			X		X		Very fire retardant; high in mineral content. Very susceptible to rabbit damage.
<i>A. gardneri</i> Gardner's saltbush, Utah	O	X	X	X		X		X		As above. Produces root sprouts.
<i>A. mulleri</i> ² Muller's saltbush, Australia	X	O	O	X		X	X			Low in frost tolerance. Prolific seeder.
<i>A. semibaccata</i> ² Australian saltbush, Australia (Nat. U.S.)	X	O	O	X	O	X	X			Short lived; low in frost tolerance; naturalized.
<i>Baccharis pilularis</i> Prostrate or dwarf baccharis, California	X	X	O	O	X ¹	X		X		Adapted to moist or irrigated sites.

Table 3 Relative performance of low-growing¹ shrub species for plantings to reduce fire hazards in southern California brushland clearings Continued

Species and native source	Elevation range of adaptability			How established			Growth rate			Remarks
	<2000 ft (<610 m)	2000 to 4000 ft	>4000 ft (>1220 m)	Direct seeding	Stem cuttings	Rooted transplant	Fast	Med.	Slow	
<i>Atriplex falcata</i> "Falcata" salt- bush, Great Basin region	O	O	?	X	O	X			X	Poorly adapted, low survival and poor vigor and cover.
<i>A. inflata</i> ² Flat-topped saltbush, Australia	X	O	O	X	O	X	X			Short-lived; sensitive to frost.
<i>A. nuttallii</i> Nuttall's salt- bush, Great Basin region	O	O	X	X	O	X			X	Poorly adapted; low survival and poor vigor; stem layers.
<i>Ceanothus griseus</i> var. <i>horizontalis</i> Carmel creeper ceanothus, California	O	X	X	O	O	X			X	Poorly adapted except on very moist or irrigated sites; very susceptible to rabbits.
<i>Ceanothus</i> <i>prostratus</i> Prostrate ceano- thus or squaw- carpet, Sierra-Nevada, Cascade, Calif.	O	O	X	X	O	X		X		Attractive. Excellent on moist sites above 5000 ft Stem layers.
<i>Galenia</i> <i>pubescens</i> ² Green galenia, South Africa (Nat. Australia)	X	O	O	X	O	X	X			Prolific seeder; sensitive to frosts. Possibly toxic to livestock.
<i>Myoporum</i> <i>parvifolium</i> ² Myoporum; "Horshum" cultivar, Australia	O	X	O	O	X ³	X		X		Adapted to moist or irrigated sites; stem layers.
<u>Poor performance</u>										
<i>Arctostaphylos</i> <i>uva-ursi</i> Bearberry; Kinnikinnick, North America, Europe, and Asia	O	O	X	O	O	X			X	Very diffi- cult to root; plantings all failed.
<i>C. gloriosus</i> Pt. Reyes ceanothus, California	X	X	O	O	O	X		X		As above.

Table 3—Relative performance of low-growing¹ shrub species for plantings to reduce fire hazards in southern California brushland clearings—Continued

Species and native source	Elevation range of adaptability			How established			Growth rate			Remarks
	<2000 ft (<610 m)	2000 to 4000 ft	>4000 ft (>1220 m)	Direct seeding	Stem cuttings	Rooted transplant	Fast	Med.	Slow	
<i>C. maritimus</i> Maritimus ceanothus, California	O	X	X	O	O	X			X	Drought hardy, but very slow in growth.
<i>Ceratoides lanata</i> Winterfat, Western United States	O	X	O	X	O	X			X	Poorly adapted; low in survival and poor in vigor; has fine porous foliage. Poor cover plant.
<i>Chamaebatia foliolosa</i> Sierra mountain misery, California	O	X	O	O	O	X			X	Very slow in growth; has fine porous foliage; quite flammable.
<i>Genista lydia</i> ² Genista, Greece	O	X	O	O	O	X			X	Very slow in growth; has sparse open foliage.
<i>Lippia canescens</i> var. <i>repens</i> Creeping lippia, United States	O	X	O	O	O	X			X	Very slow in growth; has sparse open foliage.
<i>Nama lobzii</i> Woolly nama, California	O	X	X	O	O	X	X			Produces root sprouts; aggressive on disturbed sites; susceptible to gopher damage.
<i>N. rothrockii</i> Rothrock nama, California	O	O	O	O	O	X				Poorly adapted; all plantings failed.
<i>Osteospermum fruticosum</i> ² Trailing south African daisy, South Africa	X	O	O	O	O	X		X		Probably suited to moist or irrigated sites; susceptible to frost damage.
<i>O. pachypteris</i> ² Osteospermum, South Africa	X	O	O	O	O	X		X		As above.

¹ Generally less than 1 foot tall.

² Exotic species, including some naturalized in California.

³ Cuttings with layered rootlets.

Table 4—Semiprostrate and tall shrub species useful for plantings in southern California brushland clearings

Species and native source	Elevation range of adaptability			How established			Growth rate			Remarks
	<2000 ft (<610 m)	2000 to 4000 ft	>4000 ft (>1220 m)	Direct seeding	Stem cuttings	Rooted transplant	Fast	Med.	Slow	
Semiprostrate shrubs¹				<u>Good performance</u>						
<i>Cistus crispus</i> Descanso rockrose, Mediterranean region	X	X	?	O	O	X		X		Dense foliage; stem layers; attractive flowers.
				<u>Fair performance</u>						
<i>Arctostaphylos myrtifolia</i> Ione manzanita, California	O	X	X	O	O	X			X	Slow growth.
<i>Arctostaphylos confertifolia</i> Shadscale salt- bush, Western United States	O	X	X	O	O	X		X		High mineral content; best on basic soils.
<i>Ceanothus masonii</i> Mason's ceanothus, California	O	?	X	O	O	X		X		Has sparse open foliage; stem layers.
Tall shrubs¹				<u>Fair performance</u>						
<i>Atriplex canescens</i> Fourwing salt- bush or chamiza, Western North America	X	X	?	X	O	X	X			Excellent shrub for many uses; high mineral and moisture content, easily estab- lished by seeding.
<i>Atriplex polycarpa</i> Allscale or desert saltbush, California and Arizona	O	X	?	X	O	X	X			do.
<i>Cistus villosus</i> Purple rock- rose, Medi- terranean region	X	X	X	O	X	X	X			Three to 5 feet tall, moderately drought and frost tolerant, flammable when foliage dries, showy flowers

¹ Semiprostrate shrubs are usually 1 to 3 feet (0.3 to 0.9 m) tall; tall shrubs are usually more than 3 feet tall.

Table 5—Plants not considered suitable for use to reduce fire hazards

Species and native source	Reasons why plants are not suitable
<i>Artemisia aucheri</i> Iran	Foliage too fine and porous, numerous small twigs, growing to 2 feet high. Appears to be equally as flammable as our native <i>Artemisia</i> .
<i>Artemisia herba-alba</i> Iran	As above.
<i>Artemisia cana</i> var. <i>bolanderi</i> Western United States	Poor survival, fine porous foliage that probably is very flammable.
<i>Atriplex elegans</i> Wheelscale saltbush, Western United States	Medium-sized shrub to 3 feet tall; short-lived perennial or annual; poor seedling establishment.
<i>Atriplex halimus</i> Mediterranean saltbush, Mediterranean region	Plants too massive and fuel volume too great; up to 8 feet high with crown at least that wide; numerous relatively small twigs that when dry are likely to burn with high intensity and heat output; not tolerant to low temperature.
<i>Atriplex hymenelytra</i> Desert holly, California	Not adapted except on saline to alkaline soils; grows to 3 feet tall, but otherwise acceptable.
<i>Atriplex lentiformis</i> Big or quailbush saltbush, California	Large shrub to 8 feet tall; high fuel volume.
<i>Atriplex lentiformis</i> var. <i>Breweri</i> Brewer's saltbush, California	Less cold tolerant, otherwise similar to <i>A. lentiformis</i> .
<i>Atriplex leucoclada</i> var. <i>turcomanica</i> Turcoman saltbush, Western Australia (Israel selection)	Frost sensitive, survives only below 2000 feet (610 m); fine foliage, probably quite flammable.
<i>Atriplex nummularia</i> Oldman wormwood, Australia	Somewhat larger but otherwise similar to <i>A. halimus</i> ; plants are massive and produce very high fuel volume.
<i>Atriplex Torreyi</i> Torrey's saltbush, California	More cold tolerant, otherwise similar to <i>A. lentiformis</i> .
<i>Atriplex veruciferum</i> Iran	Fine foliage and numerous small twigs on upstanding shrub 2 to 3 feet (.6 to .9 m) tall. The growth form resembles Russian thistle (<i>Salsola kali</i> L. var. <i>tenuifolia</i>) tumbleweed and when dry may be equally as flammable.
<i>Cistus ladaniferus</i> Gum rockrose, Mediterranean region	Very tall upstanding plant; drought tolerant but quite flammable in late summer and fall; attractive flowers.
<i>Cistus salvaefolius</i> French Morocco	Relatively large, 3 to 4 feet (.9 to 1.2 m) high with fine foliage and numerous small twigs; probably equally or more flammable than <i>C. villosus</i> , but seems to have fewer advantages.
<i>Kochia prostrata</i> Prostrate summer cypress or "golden plant of Russia," Iran	Foliage too fine, numerous erect small stems up to 1½ feet (46 cm) tall; potential flash-fire fuel when dry in late summer. May become as flashy as annual grasslands. Is palatable so could be grazed.
<i>Lavandula stoechs</i> French lavender, French Morocco	Plants somewhat too tall—up to 3 feet (.9 m). The rather sparse upstanding branches have relatively fine foliage resembling that of California buckwheat (<i>Eriogonum fasciculatum</i>). This plant was grown from seed inadvertently included with another species sent from French Morocco. Species is used primarily for preparing perfume from its flowers.
<i>Opuntia ficus-indica</i> Mission cactus, Mexico	Too susceptible to damage by many agents including temperatures less than 25° F, and damage by small mammals and domestic livestock; has limited adaptability and suitability for use in reducing fire hazards.
<i>Opuntia serpentina</i> x <i>O. prolifera</i> Cholla, Western United States	Much too spiny, very slow growth and relatively weak or poor cover plant. High safety hazard to fire control personnel.

Table 5—Plants not considered suitable for use to reduce fire hazards (Continued)

Species and native source	Reasons why plants are not suitable
<i>Purshia glandulosa</i> Desert bitterbrush, California to Utah	Mature plants quite flammable; primary use as browse and as cover on disturbed sites; very drought tolerant.
<i>Purshia tridentata</i> Antelope bitterbrush, Western United States	More cold but less drought tolerant than <i>P. glandulosa</i> ; excellent browse and cover for disturbed sites.
<i>Rosmarinus officinalis</i> Rosemary, Mediterranean region	Drought tolerant; very flammable; aromatic.
<i>Tamarix aphylla</i> Athel tree, Mediterranean region	Too high volume and much fine foliage. It is susceptible to freezing and tops kill back at 20 to 25° F (–7 to –4° C) on young plants grown from cuttings.

Table 6—Silica-free ash and crude fat content of foliage (leaves and current year's stem leaders) of shrub species considered for plantings to reduce fire hazards on wildland areas in southern California

Species	Silica-free ash ¹	Crude fat ¹
Chamise (<i>Adenostoma fasciculatum</i>)	2.8 to 5.3	5.1
Caucasian artemisia (<i>Artemisia caucasica</i>)	8.3	3.5
Sweet sagebrush (<i>Artemisia ludoviciana</i> var. <i>incompta</i>)	11.9	5.2
Fourwing saltbush (<i>Atriplex canescens</i>)	12.4 to 19.1	0.9
Castlevalley saltbush (<i>A. cuneata</i>)	18.0	2.3
Shadscale saltbush (<i>A. confertifolia</i>)	21.6 to 27.5	2.0 to 2.9 ²
Gardner's saltbush (<i>A. gardneri</i>)	23.5 to 25.3	2.2 to 2.5
Muller's saltbush (<i>A. mulleri</i>)	21.1	2.9
Allscale or desert saltbush (<i>A. polycarpa</i>)	11.3 to 20.5	1.5 to 3.5 ³
Silver or sweet saltbush (<i>A. rhagodioides</i>)	12.8	1.7
Australian or creeping saltbush (<i>A. semibaccata</i>)	13.4 to 19.1	0.7 to 2.3 ⁴
Descanso rockrose (<i>Cistus crispus</i>)	3.9 to 8.8	2.6
Gum rockrose (<i>C. ladaniferus</i>)	5.0 to 10.4	—
Purple rockrose (<i>C. villosus</i>)	4.7 to 9.0	—
Green galenia (<i>Galenia pubescens</i>)	18.3	4.3
Rosemary (<i>Rosmarinus officinalis</i>)	5.5 to 7.2	—
Creeping or Sonoma sage (<i>Salvia sonomensis</i>)	4.7 to 7.1	10.1
Cypress lavendercotton (<i>Santolina chamaecyparissus</i>)	5.3 to 9.0	—
Green lavendercotton (<i>S. virens</i>)	6.0 to 7.9	—

¹ Where no range is given, a single sample was used. Other entries represent a range that is mainly seasonal. Except as otherwise cited, analyses were made at Northern or Riverside Forest Fire Laboratory.

² Cook and others 1954.

³ Chatterton 1970.

⁴ Russell 1946.

ladaniferus L., and *C. villosus* L.), saltbush (*Atriplex canescens* [Pursh] Nutt. and *A. polycarpa* [Torr.] Wats.), and rosemary (*Rosmarinus officinalis*). The saltbushes and creeping sage were the only ones within these groups that were readily established over a wide range of conditions from direct seedings as well as transplants; however, saltbush species were quite susceptible to damage by rabbits clipping the plants, especially during the first year.

The following sections describe most of the shrubs we are testing for planting in cleared brushland areas in southern California. The comments insofar as possible describe the plant's characteristics, denote the locale of its normal occurrence, state its usefulness for wildland plantings, and include directions for establishing the plant. For some species, the silica-free ash and crude fat contents were analyzed (table 6). Completeness of these comments varies because we have been able to study some species more thoroughly or over a longer time than others.

Sources for seed for many species will have to be developed or enlarged before extensive seedings can be made. Only a few of these plants are normally available at nurseries; therefore it is advisable to make arrangements at least 1 year ahead so that the seed can be obtained and plants propagated and ready when needed.

Low-growing Shrubs

Widely Adapted

Creeping or Sonoma sage (*Salvia sonomensis* Greene.)—Creeping or Sonoma sage is an aromatic, semiprostrate suffrutescent plant found in the chaparral zone along the Sierra Nevada and the Coastal ranges in California at elevations below 6000 feet (1830 m). It grows on relatively shallow, moderately acid-to-neutral soils, where annual precipitation averages 15 to 40 inches (38 to 100 cm) and temperatures range from about 15° to over 100° F (−10° to 38° C). It can withstand some frost, and, once it is established, considerable drought; it does not tolerate saline or alkaline soils (Pratt and others 1971).

This plant gives excellent protection to the soil, and is valuable for fire abatement. Fire burned through creeping sage stands only one-fifth as fast as through dry annual grass and weeds, and produced less heat (Phillips and others 1972). It crowds out most of the flash fuel plants. Plants form mats, often several feet across, with low, dense foliage not more than 8 to 10 inches (20 to 25 cm) tall (fig. 5). Creeping sage is not grazed or clipped to any extent by animals, and therefore has a distinct advantage

over more palatable shrub species. It is adaptable to many site conditions throughout the chaparral zone.

Creeping sage has been established successfully by direct seedings, fresh stem cuttings, and transplants. Once established, it spreads primarily by layering (rooting) along the prostrate branches.

Seedling establishment under natural conditions is very poor, but satisfactory stands have resulted from planting in clean seedbeds. The best stands developed from seed treated with gibberellic acid to break dormancy (Nord and others 1971) and planted at 1/2- to 1-inch (1.3- to 2.5-cm) depth during the late winter to early spring where there was sufficient moisture present in the soil for the plants to become established.

Survival of plants grown from seed or stem cuttings and planted in propagating tubes has consistently been high. For field plantings where watering is not feasible, the minimum recommended tube size is 2¼ by 2¼ by 8 inches (5.7 by 5.7 by 20 cm) with open bottoms so roots may readily grow into the soil below. Bare-rooted transplants can be grown in the nursery, or wildlings suitable for this purpose may occasionally be found, especially on areas where fire has burned through creeping sage stands. The Corte Madera area in San Diego County burned in 1970, and subsequently produced several thousand creeping sage seedlings per acre, many of which were lifted and used for plantings throughout southern California in 1973. Bare root transplants should have roots 8 to 12 inches (20 to 30 cm) long and should be planted in moist soil during the early spring before the plants leaf out to any extent.

Plants are easily propagated from stem cuttings taken at almost any season of the year without benefit of hormone treatment (Nord and Goodin 1970), although best rooting has developed from "hardened" stem or branch sections taken during the late winter. When planted in the field, cuttings with or without attached naturally formed rootlets should be at least 15 inches (38 cm) long and set almost as deep, with soil firmly tamped around the base. Early spring is the time for planting cuttings. The soil is warm enough to induce rooting while there is still adequate soil moisture.

The seed—of which there are about one-half million per pound (1100 per g)—is currently available only by collecting from natural stands. As it matures in mid-May or early June, the spikes can be gathered and spread to dry thoroughly. Later the seed can be readily separated, cleaned and graded by means of threshers, hammermills, and ordinary fanning mills equipped with proper sieves. Seed retains high via-



Figure 5—Creeping sage, a prostrate shrub native to California, forms a dense mat which tends to exclude most annual plants. Its blue flower stalks beautify the landscape in the spring: Here, a single row at Vista Grande (A) has spread to form mats up to 12 feet wide in 6 years; a creeping sage planting made 6 years previously at the Nixon enclosure (B) has spread several feet laterally and has inhibited annual grass growth shown in the foreground.



bility for 4 years and probably much longer when stored in airtight containers at refrigerator temperatures (35° F, 2° C), with or without the recommended gibberellic acid treatment to break seed dormancy.

Creeping sage does have some shortcomings. It does not resprout from either roots or stems following burns; however, new stands may develop from seedlings that appear following fires. It is highly susceptible to weed killers and thus would need to be reestablished should it be sprayed with herbicides, as has happened along fuelbreaks and roadways in some

areas. Moisture content of foliage goes below 60 percent during the late summer and early fall, and foliage will then burn if there is much dead litter to carry the fire.

Gray and green lavendercotton (*Santolina chamaecyparissus* L. and *S. virens*)—Gray and green lavendercotton, native to the Mediterranean Region, are frequently grown in gardens and have occasionally become locally established in parts of central and southern California (Munz and Keck 1959). Both species are low to semierect, compact, aromatic evergreen subshrubs with numerous small erect to semi-

decumbent branches and fine, porous foliage (*fig. 6*). They have a fibrous root system that penetrates quite deeply and widely into the soil. Green lavendercotton plants, up to 30 inches (76 cm) high and 4 to 5 feet (1.2 to 1.5 m) wide, are considerably larger than gray lavendercotton, which may grow to be 18 inches (45 cm) high and up to 3 feet (90 cm) across the foliar crown in good growth situations. Both species are smaller, commonly about 1 foot (30 cm), on dry sites.

Both lavendercottons provide good protection to soil; they spread to form dense cover that crowds out most annuals. Plants are not known to be grazed or clipped to any great extent by animals. Both species, but particularly gray lavendercotton, are drought tolerant, hardy, and versatile, and can be grown successfully in the low desert (Mathias and others 1961 and 1968) and throughout most of the chaparral zone in southern California. Once established, they persist under relatively harsh conditions. In the field, they spread slowly by layering along the decumbent branches, but initial establishment has been only by transplants grown from stem cuttings under intermittent mist. We know of no instances where either lavendercotton has been established on field sites by

direct seedings, nor have we observed any natural seedlings.

Rooted plants grown from stem cuttings have consistently survived and made satisfactory growth on a variety of cleared brushland and highway cut-fill sites in the coastal, San Gabriel, and San Jacinto Mountains up to 5000 feet (1524 m) elevations. When planted where weedy competition was removed immediately preceding planting, 75 percent or more of the potted lavendercotton plants were growing actively 2 years after planting without supplemental irrigation. Growth, recorded in 1969 after 2 years, was as follows:

	<u>Gray</u> <u>lavendercotton</u>	<u>Green</u> <u>lavendercotton</u>
Site and elevation:		
Nixon (3500 feet):		
Survival, percent	85	95
Height, inches	12	20
Crown diameter, inches	20	30
Vista Grande (5000 feet):		
Survival, percent	100	95
Height, inches	11	21
Crown diameter, inches	28	44



Figure 6—Lavendercottons or santolinas are shown here growing at 3500 feet elevation in southern California. Where planted to reduce fire hazards, the gray lavendercotton (*right or foreground*) is preferred because of its lower growth habit and lower fuel volume than green lavendercotton (*left or background*).

These plantings remain healthy in 1975; however, in Los Angeles County, some stands have faded out within 5 years (pers. commun., Arthur Arndt).

Flowering heads were formed by both species beginning the first year, but no viable seed developed. Stem layering that developed during the second year was frequently observed on gray lavendercotton but only rarely on green lavendercotton plants.

The mineral or ash content and fuel moisture in mixed old and new growth green leaves and twigs to 1/8 inch (3.2 mm) diameter varies considerably according to the season and to a lesser extent between the two species. The following analysis is of samples taken from 2- and 3-year-old plants at Nixon plot in 1971 and 1972:

Sampling date:	Gray		Green	
	<u>lavendercotton</u>		<u>lavendercotton</u>	
	<u>Moisture</u>	<u>Ash</u>	<u>Moisture</u>	<u>Ash</u>
	—— Percent of dry weight ——			
Late May 1971	271	9.0	327	7.9
Mid-July 1971	44	5.8	44	5.8
Early October 1971	47	7.7	78	7.0
Early April 1972	398	10.9	500	12.0
Mid-July 1972	83	7.6	92	6.3
Late September 1972	67	5.3	59	6.0

The foliage dries out enough to make these plants susceptible to burning. The fine foliage provides a porous fuel bed that somewhat resembles grassland fuels. Wildland fire will most likely burn rapidly through the foliage when fuel moisture is low as was recorded in 1971, particularly if there is dead fuel to carry the fire.

The chief value of these two lavendercottons is their ability to grow in dry situations, and their usually low fuel volume. Gray lavendercotton is preferred over the green.

Restricted in Adaptability or Usefulness

Caucasian artemisia (*Artemisia caucasica* Willd.)—Caucasian artemisia, native to plains and foothills of the Black Sea and Caucasus areas, USSR,² is a low-growing suffrutescent subshrub of the composite family. It is an attractive silver-colored plant that forms a thick turflike evergreen cover. It usually grows about 4 inches (10 cm) high, except for the nonpersistent erect flower stalks which reach 12 inches (30 cm). The prostrate branches root as they

spread and plants form huge mats, especially when grown in full sunlight. It tolerates some shade, but is not as thrifty nor foliage as dense as when growing in sunny situations. Plants grow satisfactorily on a wide variety of sites, particularly with irrigation from hot, low elevations up to 5000 feet (1524 m) or higher, in several parts of California and other western States (Idaho, Utah, and Washington). It is adapted to a wide variety of soils, and a pH range of 6.0 to 8.0.

Plants in this country originated from a single clone, developed from seed obtained from USSR in 1966 (PI #314-441; UCD #66-1178), and propagated by the University of California at Davis in a cooperative program with the Forest Service. The plants flower abundantly, but no viable seed has been obtained from any plantings. Apparently this particular ecotype or clone strain, like certain other *Artemisias*, is self-sterile.

Plants can be readily rooted from cuttings 3 to 4 inches (8 to 10 cm) long containing about 2 inches (5 cm) of hardened stem sections, in sand or sponge rock under occasional intermittent mist. Cuttings are susceptible to damping-off fungus and therefore care must be used to avoid excessively damp conditions in mist chambers. Also, crown masses from established plants can be sectioned and planted in much the same manner commonly used with "plugging" turf plants such as dichondra or bermudagrass.

Plants produced from stem cuttings or divisions or sections of stem having roots formed naturally from stem layers can be transplanted either in pots or bare rooted between late fall or early spring when the ground is still wet. Survival is high and growth rapid under irrigation, even without fertilizing throughout southern California. Spaced at 3-foot (0.9-m) intervals, plants spread up to 2 feet (0.6 m) outward per year, and cover the ground within a 2-year period (fig. 7).

Under dryland situations, survival and growth is considerably less than under irrigation. Plantings made at the Nixon and Vista Grande sites in southern California had 5 and 35 percent survival and crown diameters were 3 and 9 inches (8 and 23 cm) respectively, during a 2-year period when precipitation was about 15 inches (38 cm) annually.

Most of the mortality to Caucasian artemisia plants has been caused by gophers digging under and cutting off roots below the crowns rather than by dry soil conditions. Rabbits are also known to clip the foliage. Occasionally, dense stands may be damaged by fungus organisms, especially if plants are kept very moist from too frequent sprinkling or during prolonged humid conditions.

²Flora URSS (Flora Unionis Rerumpublicarum Socialisticarum Sovieticarum) XXVI. Editio Academiae Scientiarum URSS. Mocqua, Leningrad. p. 492-493. (Trans. by Patrick Farlan, U.C., Riverside, Jan. 29, 1973.)



Figure 7—Caucasian artemisia is a recent introduction from the Soviet Union. It shows promise as a low-growing, drought- and cold-tolerant plant useful to reduce fire hazards, for erosion control, and as ornamental ground cover. Plants spread up to 2 feet outward per year under irrigation and spaced at 3-foot intervals cover the ground within 2 years.

One might suspect that when this plant becomes dry it would burn as do most other *Artemisia* (sagebrush) species. Its ash content, about 8 percent, and crude fat content, 4 percent (table 6), is intermediate between that in known flammable and slow-burning species. However, because of its very low growth habit and small fuel volume, any fires that might develop would be of low intensity and heat output; therefore, to have it occupy a site could reduce the fire hazard significantly.

Caucasian artemisia can then be recommended as a low-volume ground cover that is admirable for ornamental landscape use throughout a wide range of site conditions.

Castlevalley saltbush (*Atriplex cuneata* A. Nels.)—This saltbush is native to western Colorado, central Utah, and southward. It grows on alkaline soils, but in our tests tolerated soils of neutral or slightly acid reaction. It is low-growing up to 1 foot (30 cm) tall and 2 to 3 feet (60 to 90 cm) across the coarse textured, dense crown that spreads to a moderate extent by means of stem layers along decumbent branches. It is one of the most fire resistant plants existing anywhere. It has unusually high mineral con-

tent, with 20 to 25 percent of the foliage dry weight being ash constituents. The foliage is succulent; the moisture content is well above 100 percent much of the year. It is extremely palatable and nutritious for livestock, and where it grows is regarded as equal to alfalfa hay as feed. For us this palatability is a liability, however, as the plant is very susceptible to rabbit clipping and damage. Seed production is less than for many other saltbushes, and harder to collect. Consequently, there is no commercial seed supply, but seed can be collected. Seed orchards should be established to supply seed. Plants are easily propagated from stem cuttings, and this has been the main source of planting stock for our tests.

Gardner's saltbush (*Atriplex gardneri* [Moq.] D. Dietr.)—Gardner's saltbush is a low-growing shrub native to the Great Basin section of Western United States. It is woody at the base, seldom over a foot (30 cm) tall. It tends to develop nearly pure stands or colonies, sometimes many feet across. Unlike most shrubs, Gardner's saltbush reproduces by root sprouts (Nord and others 1969). Numerous buds and shoots originate from lateral roots which are 2 to 9 feet (0.6 to 2.7 m) long, lying about a foot below the surface.

These root sprouts can be dug up and used as planting stock. The plant can also be produced from seed, although the seed is harder to collect and lower in germination percentage than fourwing saltbush seed. In southern California, seeding results at 3500 feet (1067 m) elevation were much better than at 5000 feet (1524 m), 1/2 inch (1.3 cm) seeding depth was better than 1 inch (2.5 cm), and mid- to late-spring when soil temperatures were 60° to 65° F (15° to 18° C) and soil moisture was still adequate was the best time for seeding Gardner's saltbush (Nord and others 1971).

Muller's saltbush (*Atriplex mulleri* Benth.)

Muller's saltbush is a semiprostrate, suffrutescent shrub with light green foliage that grows about a foot (30 cm) high and 2 to 3 feet (0.6 to 0.9 m) in diameter. It is considered an annual in its native Australia (Black 1963), but has maintained a biennial or perennial habit in southern California. Plants are drought resistant, surviving with as little as 10 inches (25 cm) of rainfall, but freeze at temperatures around 20° F (-7° C). It appears adapted to diverse soil textures, but needs a pH range of 6.0 to 8.0. In most respects, its adaptability is similar to that of Australian saltbush (*A. semibaccata*). Muller's saltbush is

a good ground cover plant and, within its natural range, is considered a useful forage plant for grazing. Its forage potential in this country has not been determined; however, we observed one instance where horses avidly grazed most of this saltbush on a planting in San Diego County.

Chemical analysis of Muller's saltbush foliage showed a relatively high ash content, about 20 percent. In other saltbushes, high mineral content is usually associated with relatively high fuel moisture throughout much of the year.

The seed develops from small inconspicuous flowers on monocious plants, and ripens between July and late fall. The ripe seed loosens and may be harvested quite readily, either directly from the plant by suction harvesters (fig. 8), or by combines. Threshers can also be used after plants are cut and dried. There are about 115,000 generally well-filled seed per pound (254 per g). Numerous seedlings develop around established plants, especially where there has been some soil disturbance.

Seed yield from plants on irrigated plots was greater when harvesting was in the fall than during late summer, averaging 82 grams per plant compared to 38 grams for a July harvest. However, germination was somewhat lower—13 percent, and 20 percent for



Figure 8—Seed of Muller's saltbush can be harvested with a suction collector as here at the Forest Fire Laboratory nursery, Riverside, California, July 1973.

seed collected in July. This unexplained difference was statistically significant. Moist seed starts to germinate within 2 to 3 days and continues for about 3 to 4 weeks. The germination percentage is increased at least three times, and about half the germination time is required, if the seed coat is removed. The seed coat evidently contains an inhibitor similar to that found in other *Atriplex* seeds (Gerard 1965; Koller 1957; Nord and Van Atta 1960; Springfield 1970). The seed is readily loosened by a hammermill equipped with 1/16-inch diameter sieve, and then can be separated from the coats in a clipper mill.

Seed should be planted shallowly—1/4 to 1 inch (0.6 to 2.5 cm) deep—as for most other *Atriplex* species (Nord and others 1971), during late winter to midspring while soil moisture is available and the soil is warm. On weed-free seedbeds, 6 pounds of seed per acre (6.7 kg/ha) should be adequate where this species is sown alone. Where rabbits or other small mammals are likely to damage plantings, some protection will be needed. With irrigation, stands containing 5000 Muller's saltbush plants per acre (12,350 per ha) might produce 600 to 700 pounds (272 to 318 kg) of seed. Greatest seed harvest would result from a July suctioning, and a fall combining.

Desirable characteristics of Muller's saltbush include its low growth habit, abundant seed production, ease of establishment by direct seeding, rapid growth, and high mineral content. For these reasons, it appears to be a desirable plant on adapted sites for fire hazard reduction, and grazing by domestic and wild animals. However, we can only recommend it on a test basis at present. We do not yet know how durable stands will be in competition with native vegetation. Establishment may be a problem because of injury or destruction by rodents, and seed is not readily available. Should a demand develop, however, large amounts of this seed could be produced within a year or two, and mechanical harvesting is feasible.

Australian saltbush (*Atriplex semibaccata* R. Br.)—Australian saltbush, a native of Australia, was introduced experimentally about 1877 (Hall and Clements 1923; University of California Agriculture Experiment Station [n.d.]³) and naturalized in Cali-

fornia, Arizona, and New Mexico. It is a light green prostrate plant growing a few inches high and in mats up to 4 feet (1.2 m) across. It occurs along roads or other disturbed sites, mostly on saline soils below 3000 feet (914 m) elevations where temperatures do not drop much below 20° F (−7° C) (McKee 1919). It withstands considerable drought and hot weather. Almost from its introduction, Australian saltbush was acclaimed, particularly for grazing use, but the high hopes regarding its value were not realized in most areas. It does, however, provide some forage where it has naturalized and when planted to provide cover on disturbed areas (Sampson and Jespersen 1963).

This plant grows strong and vigorous the first year, but within a few years the stand weakens and often thins out or disappears, except where the ground is disturbed in some manner. Disturbance stimulates germination and establishment of new seedlings. Otherwise, stands are generally replaced by other plants—mostly herbaceous species—as the saltbush declines.

Australian saltbush is monocious, unlike many *Atriplex*. It produces an abundance of red, fleshy fruit that compresses and turns brown to black as it ripens, usually over a period of several weeks during late summer and fall. The seed ripens unevenly, and cannot be effectively collected directly from the plant. Instead, it is usually gathered from the ground by means of suction collectors designed for this purpose. The 120,000 seed per pound (265 per g) usually are filled and germinate within a few days when growing conditions are favorable without special treatment. Seed should be planted shallowly, not more than 1/4 inch (0.6 cm) deep, during late winter or very early spring while the soil is moist but after it has warmed. Three to four pounds of seed per acre (3.4 to 4.5 kg/ha) is generally sufficient when sown alone. This seed is available and currently costs about \$7.50 per pound (\$16.52 per kg) from commercial seed dealers.

Australian saltbush has a relatively high mineral content—up to 20 percent ash in the foliage—and retains a high fuel moisture content throughout most of the year. Its high salt and fuel moisture contents and low growing habit make it desirable for reducing fire hazard. However, this benefit generally does not hold for more than a few years because of its short life span.

Like many saltbushes, this one is very susceptible to damage by rabbits, squirrels, and other small mammals that clip off the plants before they can become established. No effective means of preventing depredation by these agents has been developed. The

³University of California Agriculture Experiment Station. [n.d.]. *Early history of Australian saltbushes (*Atriplex* sp.) and other halophytes introduced into the United States, 1877 to 1901*. A consolidation of California Experiment Station reports between 1877 to 1901 pertaining to plantings primarily for grazing use. (Copy on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Exp. Stn., Riverside, Calif.)

species is also known to be a host plant for *Eutettix tenella*, the insect that carries curly-top disease of sugar beets, and thus it should not be introduced or planted in areas where it may affect this crop (Severin and Basinger 1922).

Dwarf baccharis or dwarf coyote brush (*Baccharis pilularis* DC.)—Dwarf baccharis is an attractive low-growing evergreen shrub, usually no more than 1 foot (30 cm) high. It spreads by means of root sprouts and stem layers along the prostrate branches to form dense mats that may be 10 feet (3.0 m) across on favorable sites. Its deeply penetrating root system and dense foliage make it valuable for erosion control, especially along cut and fill slopes. Sprouting following fire is quite common (Sampson and Jespersen 1963).

The plant is native to central California coastal areas, and is only moderately tolerant of drought or cold. Therefore, its use is limited to about 3500 feet (1067 m) elevation, and to sites near the coast unless supplemental irrigation is provided. Its sensitivity to herbicides such as 2,4-D (Leonard and Harvey 1965) may also limit its use.

The foliage has about 8 percent ash content, about the same reported for other baccharis species. This is somewhat higher than that of most chaparral species, but is less than that of many halophytes and most *Atriplex* species. When considerable dead wood is mixed with living branches, and fuel moisture is low, dwarf baccharis is probably as susceptible to burning as other baccharis species known to burn fiercely (Horton 1949), but it burns with less heat output.

Seed germinates well without pretreatment; however, direct seedings are not used to any extent for either landscaping or field site plantings. Practically all plantings are from cuttings from male plants in order to maintain particularly desirable horticultural forms and to eliminate the objectionable feathery pappus found on the seed. Where large numbers of seedlings are needed, the most satisfactory method is to seed in flats or nursery beds. Tip cuttings about 1/16 inch (1.6 mm) in diameter, or slightly larger, taken between late fall and early spring, will root without need of hormone treatment when kept under intermittent mist (Everett 1957).

Rooted cuttings, preferably in pots, or rooted "wildling" plants formed naturally from either root sprouts or stem layers, can be transplanted during late winter or very early spring when the ground is still wet and preferably before new growth commences. Plants should retain as much of the root as possible and must be wrapped in wet toweling or burlap to

keep them moist while they are collected and until they are replanted in the ground.

Dwarf baccharis is seldom grazed or browsed; however, young plants are occasionally damaged or destroyed by small animals. About one-third of plants set out in early spring during one southern California test were damaged by rabbits, and a few plants were destroyed by gophers during the first year. No observable effects from animal use occurred thereafter or until all plants died from drought 2 years later.

Seedlings and stem cuttings are quite susceptible to damping-off fungus, and mildew may form to kill back portions of the older plants (Robinson 1961).

Survival of potted stock at Nixon plot, North Mountain Experimental Area, after 1 year was 53 percent. Plants averaged about 6 inches (15 cm) across the foliar crown during the first year, but less than 5 percent survived after the second year at this site. Very good first-year survival, usually 80 percent or higher, has been the experience with several other dwarf baccharis plantings made by the Los Angeles County Fire Department. These were mostly at lower elevations on sites situated near the coast and generally within the influence of marine climate.

Dwarf baccharis is an excellent landscaping shrub but, except near the coast, will generally require irrigation if it is to thrive.

Plants can be propagated from stem cuttings treated with hormone and kept under intermittent mist. This may be the only way to obtain the low-growing variety. Plants from seed have grown taller, and we believe the low-growing horticultural variety probably originated from a clonal section from Marin County. Neither the plants nor seed are currently available, but they could probably be obtained through special arrangements with nurseries or seed dealers. Seed dormancy can probably be overcome by cold stratification or chemicals such as gibberellic acid.

Prostrate ceanothus, squawcarpet (*Ceanothus prostratus* Benth.)—Prostrate ceanothus, native to the Sierra Nevada, and the Cascade and Coastal ranges in California and adjoining states, is an attractive, evergreen shrub, usually only a few inches high, that spreads to form dense mats up to 8 feet (2.4 m) across (fig. 9). The underside of many branches are lined with stem-layered roots which form new plants. The holly-shaped leaves are dull to glossy light green and the white-to-multihued-blue blossoms, borne in the leaf axils during late spring and early summer, often permeate the air with a sweet lavender fragrance.

This plant is generally found in the pine or fir



Figure 9—Prostrate ceanothus or squawcarpet is an attractive evergreen shrub that spreads to form dense mats often many feet wide. This plant is best suited to higher elevations, generally 5000 feet or higher, and prefers moister sites in southern California. (A) Shown here is a natural stand between Reno and Lake Tahoe, Nevada; and a 6-year old planting (B) at Vista Grande test site, San Bernardino National Forest, Riverside County, California.



forests at elevations between 2100 and 7000 feet (640 and 2134 m), on neutral to moderately acid soils. It withstands subzero temperatures but is only moderately drought tolerant. It grows vigorously even on infertile soils, perhaps partly because it supports nitrogen-fixing bacteria (Stewart 1967). Plantings made in southern California have not survived where soil pH was much above 7.5. It is a nonsprouter but reproduces from seed following burns.

Seed ripens during July or August, depending on the elevation and the year, and is quickly cast from the plants. When mature and dry, the fruit capsules

split open and scatter the seed, which is sought after by rodents and birds. The seed must be collected by plucking fruit capsules before they are fully ripened (about the time seed is in the hard dough stage) and then placing them in a warm, well-ventilated place to dry. Seed not released from collected capsules can be run through a seed scarifier or hammermill and separated out by a fanning mill.

There are about 41,000 prostrate ceanothus seed per pound (90 per g) (Reed 1974). This seed is dormant and requires treatment to germinate readily. The best method we have found is to place the seed in

water preheated to 170° to 180° F (77° to 82° C), allow it to soak for about 3 to 4 hours in the gradually cooling water, drain overnight or longer, then soak for about 48 hours, preferably under constant agitation, in 500 p/m gibberellic acid solution. The solution should then be drained off and, without rinsing, the seed dried thoroughly before it is planted or stored. This treatment remains effective for at least a year if seed is stored in a tightly sealed container in a refrigerator. The gibberellic acid treatment is relatively easily applied and our results show that it is at least as effective as stratification for 60 to 90 days or as other means previously recommended for breaking dormancy (Frolich 1967).

In tests at widely separated locations in the western states, prostrate ceanothus has made its best growth on soils derived from granitic parent materials. These were loose, coarse textured, well aerated, and well drained (Brown and others 1971).

Rooted plants grown from seed or stem cuttings in propagating tubes have shown fair to good survival and made rapid growth in southern California when they were planted at not less than 5000 feet (1524 m) elevation. At lower elevations, plantings either did not establish or grew poorly. A fair stand developed from seed treated with gibberellic acid to break dormancy and planted at 1-inch (2.5-cm) depth during February at the Nixon plot, but similar seedlings made about a month later at the Vista Grande plot failed to produce a stand of any consequence. Prostrate ceanothus should probably be seeded sometime during the late fall or winter when soil within the seed zone remains moist throughout the germination period.

Seed as well as young plants are quite susceptible to small rodent or rabbit damage. Seedling emergence was 35 times greater from spot plantings protected with wire mesh domes than from unprotected spots at the Nixon plot. Rodents mined out and removed practically all seed, including a portion that had been treated with a 0.5 percent Endrin solution intended to be a rodent repellent (Radwin and others 1970). More than 75 percent of the plants grown from seed at the Nixon plot were destroyed during the first growing season and plants not killed were badly stunted from severe clipping.

Plants are readily propagated from stem cuttings taken during late summer or fall, treated with a hormone powder dip (Brown and others 1971), and kept under intermittent mist. They can also be grown from seed and put into propagating pots; 2 by 2 by 8 inches (5 by 5 by 20 cm) is a good pot size for planting on field sites. Potted stock is commercially available, with plants costing about \$1.00 each at the nursery. Seed,

generally of good quality, is also available from a few dealers specializing in wildland seed; prices quoted range up to \$50 per pound. There appears to be good potential for growing this plant to produce seed that can be harvested. For example, we collected over 4 pounds (1.8 kg) of prostrate ceanothus seed from 56 plants established between 1965 and 1967 that now cover about 1200 square feet (112 m²) at the Vista Grande plot. About 2 man-hours were expended per pound (4 man-hours per kg) of seed collected.

Prostrate ceanothus in many respects is the ideal plant for reduction of fire hazard, and it is a very attractive ground cover as well. Unfortunately, we can only recommend it for higher elevations.

Green galenia (*Galenia pubescens* [Eckl. & Zeyh.] Druce (1917))—Green galenia, a member of the carpetweed family (Aizoaceae), is a native of South Africa but naturalized in coastal regions of Australia. It is a dense, spreading, suffrutescent perennial, usually about 1 to 2 feet (30 to 60 cm) high and several feet across. Foliage is dark green with innumerable small, inconspicuous white flowers. Stems are mostly prostrate and succulent except near the roots where they tend to be woody. They occasionally stem layer to form new plants. This plant species will require 15 inches (38 cm) of rainfall in the coastal zone, and 20 inches (50 cm) in inland southern California—about the same as perennial grasses. It does well in moderately acid to slightly basic soils. It does not appear to withstand temperatures less than about 20° F (−7° C). At 25° F (−4° C) we found frost damage, but plants survived; all plants were killed when temperatures dropped to 18° F (−8° C).⁴

Galenia plants grow very rapidly; in the nursery they spread outward at a rate of about 5 feet (1.5 m) (fig. 10) per year, and on dryland sites from 2 to 3 feet (0.6 to 0.9 m). Galenia and swamp saltbush (*Atriplex rhagodioides*) seedlings transplanted onto a Santa Monica Mountain road cut at 1800 feet (550 m) elevation grew fastest among 11 different species, mostly low-growing shrubs, planted at the site. Within 2 months, plants of both these species increased up to four times in size.⁴

Green galenia bears seed in great abundance, beginning the first year. It is very tiny, about 1,700,000 per pound (3800 per gram), and of good quality. Germination in petri dish tests averaged 74 percent,

⁴Radtko, Klaus. 1973. *Low fuel volume plants study report 1972-73*. U.S. Forest Serv. Coop. Agree. no. 21-235. 27 p. (Rep. on file at Forest Fire Laboratory, Pacific Southwest Forest and Range Exp. Stn., Riverside, Calif.)



Figure 10—Green galenia can be used to slow down wildfires, but because of its prolific seed production and ability to naturalize, especially on disturbed sites, it might become a troublesome weed if grown near croplands. Here, a single wildling plant growing at edge of nursery passageway under good site conditions has spread to be 20 feet diameter in 4 years.

reaching a peak in 5 days and practically all completed within a 10-day period. We collected three-fourths pound (340 g) of seed from a pair of 2-year-old plants which covered an area of 120 square feet (11.1 m²), about 20,000 seed per square foot (30 cm²) of foliage. The plant flowers all summer and fall, but the greatest abundance of seed ripens in early fall and should be harvested soon thereafter. Clumps of foliage can be cut and placed on plastic or other suitable surface to dry before seed is separated by such means as threshing, scarifying, or hammermilling. If seed can be harvested from larger stands, an acre or more, the green forage harvester could be used to gather galenia seed in the same manner used to harvest certain legumes and several grasses (Harmond and others 1961). After the seed matures, the harvester cuts, chops, and blows the foliage into a trailing hopper wagon. After curing or drying, seed can be threshed by a combine.

Plants can be propagated readily from stem cuttings rooted under intermittent mist or from seed that germinates readily without special treatment. Wildlings that often develop in abundance where this plant has been established and grown for 2 years or longer can also be transplanted either bare root or potted. A satisfactory stand was established from seedlings made in March 1973 by Los Angeles County Fire Department on a brush-cleared hillside area adjoining the Malibu nursery. Plants were up to 2 feet (60 cm) diameter at the end of the first growing season.

Plantings of galenia should be made early in the year, but after there is little likelihood of frosts. As for other small seeds, a shallow planting depth not to exceed 1/2 inch (13 mm) is indicated. One-fourth pound galenia seed per acre (280 g per ha) provides about 10 seed per square foot (100 per m²). Mixing the seed with 8 gallons of rice hulls per acre (75 l per ha) facilitates sowing and allows for good seed distribution whether planted by drill or broadcast seeded. The seed is not commercially available, but can be produced and harvested quite readily and at a reasonable cost.

Besides its susceptibility to frost, galenia has a serious limitation that may not only restrict but prevent its use in this country. Reports from South Africa⁵ mention that galenia causes a disease known as "waterpens" in sheep and goats, but no positive conclusions have been made from any tests to date. Analysis of galenia foliage by the Agricultural Research Service Poison Plant Research Laboratory show that this plant contains from about 3 to 6 percent oxalate and may be toxic to animals. Tests are still continuing, however, to determine whether galenia is safe for planting in this country.

Normally in South Africa and Australia, galenia is grazed by sheep and goats only when there is nothing else to eat. Test plantings in this country have been

⁵ Personal communication, Dr. Bernard de Winter, Director, Botanical Res. Inst., Pretoria, Republic of South Africa, April 25, 1974.

avidly eaten by deer, however, and in some places have been heavily clipped by rabbits. Because of its aggressive growth and prolific seed production, green galenia might possibly become a weed pest, but in Australia it has not been regarded as either noxious or especially troublesome.⁶ We have considered that galenia plants may build up sizeable amounts of foliage over a period of years, and that it may burn intensely when dry. However, reports from Australia, where galenia is recommended and used for plantings intended to reduce fire hazards, claim "it burns with the greatest reluctance even in the dried state, in the manner of wool" (Waddington 1970). The high—18 percent—silica-free ash content that we found in the foliage is probably responsible to a large extent for the high moisture content and low flammability of this plant.

Until more definite information is available regarding toxicity, we cannot recommend that green galenia be planted in this country except in areas where it may be controlled or if necessary completely eradicated.

Semiprostrate Shrubs

Semiprostrate shrubs are usually 1 to 3 feet (30 to 90 cm) tall.

Generally Good Performance

Rockrose (*Cistus* L.)—The rockroses, all endemic to the Mediterranean Region, have been acclaimed to be "fire resistant" or to have "fire retardant" characteristics, and consequently have been suggested for plantings that would reduce hazard from wildfire (Martin and Juhren 1954; Laure and others 1961; Ching and Stewart 1962; Juhren 1966; Montgomery and Cheo 1969 and 1971).

Unfortunately, however, the evidence is not conclusive. Foresters from Europe have told us that *Cistus* burns readily in its native habitat (Green 1965). Juhren (1966) suggested that *Cistus ladaniferus* L. was more flammable than most other *Cistus* species because of its gum-resin content: it has an ether extractive content of 19 to 21 percent dry weight compared to only 6 to 9 percent in *Cistus albidus* and other nonresinous species (pers. commun., Kenneth R. Montgomery 1975). However, Montgomery and Cheo (1971) found that the relatively thick leaves (low surface area-to-volume ratio) of *C. ladaniferus*

ignited less readily in muffle furnace tests than leaves of other *Cistus* and chaparral shrubs tested. The foliage moisture content of other *Cistus* species during the July–November fire season was near that of chamise, a shrub notorious for its flammability (Olsen 1960).

Members of the *Cistus* genus do have one characteristic of great interest—their ability to grow on wildland sites in southern California. Several have done well in test plantings, even when native shrub plantings failed (Juhren 1956 and 1972). Plantings by the authors in southern California confirm the ability of *Cistus* to grow well on dry sites.

The rockroses are drought resistant, have deep, extensive root systems, and their period of dormancy is adjusted to our winter rains and summer drought.

Most rockroses are relatively upright growing shrubs, typically 4 or 5 feet (1.2 to 1.5 m) tall, but ranging up to 8 feet (2.4 m). Thus they are not "low-growing." However, *Cistus villosus* L., the shortest of the *Cistus* species previously planted in southern California, may have some use for wildland watershed or ornamental planting. Descanso rockrose (*C. crispus*) does not grow as tall, and should have a place in our low-growing plant program.

Descanso rockrose (*Cistus crispus* L.)—A rockrose, morphologically very similar to *C. crispus*, was introduced into the United States during the late 1940's and planted at the University of Washington Arboretum (Mulligan 1953). Similar plant material, probably derived from that planted at the University of Washington, was planted at the Descanso Gardens, Los Angeles County, in 1966. Plant descendants of this material, known as "Descanso rockrose" and believed to be *Cistus crispus*, are described in this report.

This is an attractive aromatic, evergreen semiprostrate shrub usually 1½ to 2 feet (45 to 60 cm) tall. It spreads by means of stem layers along the decumbent branches to form a crown several feet wide. The light green, compact foliage provides a dense cover that excludes most herbaceous plants from developing below the crown. During the late spring and early summer, plants have numerous attractive bright rose-lavender flowers.

The Descanso rockrose is relatively drought tolerant, being able to grow satisfactorily with as little as 15 inches (38 cm) annual precipitation. It is well adapted to a wide range of soils varying from moderately coarse to medium textures between pH 5.5 to 7.7.

Plants propagated from cuttings that probably originated from a single clone at the Descanso Gar-

⁶ Personal correspondence, D. E. Symon, Dep. Agron., Waite Agric. Inst., Univ. Adelaide, South Australia, August 17, 1971.

dens have failed to produce viable seed. Most likely this clone strain (or genotype) may be self-sterile. However, viable seed have been produced and collected from the original plantings, which were apparently grown from seed representing different progenies. Plantings from this single progeny source have made satisfactory growth throughout a wide range of sites extending from near the coast to 5000 feet (1524 m) elevation, under different soil and climate conditions in southern California. Under favorable conditions, plants rooted in bands grew from 6 to 10 inches (15 to 25 cm) the first year and thereafter spread outward about 1 foot (30 cm) per year. These plants are low in palatability to livestock and rabbits, and therefore have an advantage over many other shrub species that are susceptible to these agents.

Seed ripens during late summer when the capsules or seed heads can be stripped off the plants and dried, and the seed separated and cleaned. There are about 605,000 seeds per pound or 1330 per gram, and it has high viability. Seed collected from the original plantings at Descanso Gardens had 85 percent fill. Much of the seed is dormant and will not germinate readily unless it is treated in some manner. Tests by Kenneth R. Montgomery (pers. commun., 1975) showed that treating this seed for 2 minutes in dry heat at either 150° or 185° F (65° or 85° C), or for the same period in boiling water, yielded over 80 percent germination as compared to about 30 percent for untreated seed. A 2-hour soak in 200 p/m gibberellic acid was not quite as effective as the dry heat or boiling water treatments to break dormancy and improve germination.

Descanso rockrose can probably be established by direct seedings if the seed is treated, if care is exercised in selecting sites, and if good agronomic practices are utilized in such plantings. Sufficient seed has not been available heretofore for this purpose. However, several hundred seedling plants originating from the rockrose plants at Descanso Gardens were planted in spring 1975 at the North Mountain Experimental Area to test their suitability, and also to provide a more adequate source of this seed.

The foliage of Descanso rockrose contains from 6.4 to 8.8 percent ash (table 6). Moisture content of the foliage drops below 70 percent during the late summer and fall; consequently, mature plants are susceptible to burning. However, the plant should burn with less intensity and heat output than most chaparral vegetation because of the lower growth habit and fuel volume. This plant could reduce fire hazards as well as serve other useful purposes throughout a wide range of sites in the Southwest.

Fair Performance

Lone manzanita (*Arctostaphylos myrtifolia* Parry)

—Lone manzanita is a compact, semiprostrate shrub up to 3 feet (0.9 m) tall with dense evergreen foliage (fig. 11). It is native to the Lone region along the Sierra Nevada foothills at 1000 to 1500 feet (305 to 457 m) elevations. Its native occurrence is limited to strongly acid soils—pH 2.9 to 4.0—derived from outcrops or sediments from the Lone formation (Gankin and Major 1964). It is a nonsprouter, so plants are eliminated by severe fires. New plants are occasionally formed from stem layers along decumbent branches and seedlings generally develop naturally on recently disturbed areas, but rarely in competition with older plants. Reproduction on burned stands is dependent upon soil-stored seed or seed transported onto the area from adjoining stands.

The only southern California site out of several from 1500 to 5000 feet (457 to 1524 m) elevations where lone manzanita has shown any promise was at the Vista Grande plot at 5000 feet in the San Jacinto range. Soil reaction was pH 6.0 to 6.8. Survival over a 6-year period from plantings made in 1966 and 1967 of potted wildling seedlings was 100 and 30 percent, respectively, and plants averaged about 1 foot (30 cm) high and 1 to 2 feet (30 to 60 cm) across the crowns at the end of the period. Similar plantings made at other sites were unsatisfactory; practically all plants died, usually during the first or second year. One difficulty in establishing the shrub is its slow growth, both above and below the ground surface. Not uncommonly, plants grew only 2 to 3 inches (5 to 8 cm) higher or wider each year, and roots extended only about a foot into the ground during the first growing season. This plant seems poorly adapted to coarse-textured soils like sandy loam or loamy sand, presumably because of the low water-holding capacity and rapid moisture depletion.

Lone manzanita is not well adapted and cannot be recommended for plantings intended to reduce fire hazards in most of southern California. It could be used to a limited extent as an ornamental, preferably in combination with other low-growing plants such as creeping sage or prostrate ceanothus. It is attractive because of its warm bark color, dense evergreen foliage, and symmetrical form. It could be useful for planting on brush-cleared areas in a semi-urban situation above 4000 feet (1200 m) elevation in southern California.

Mason's ceanothus (*Ceanothus masonii* McMin.)

—Mason's ceanothus, native to Marin County, California, is a semiprostrate shrub usually 1 to 2 feet (0.3



Figure 11—lone manzanita is an attractive low-growing shrub that would have limited use in plantings to reduce fire hazards. These plants at the Vista Grande site were about 1 foot tall and 2 feet wide when 9 years old. Prostrate ceanothus (*foreground*) was planted at the same time and has spread into and under the crowns of the lone manzanita to completely carpet the area.

to 0.6 m) high and up to 6 feet (1.8 m) across the crown. Plants are moderately compact with divaricate, decumbent branches that occasionally stem layer to form new plants where in contact with the ground. This species is moderately drought tolerant and withstands temperatures down to about 15° F (10° C). Like most other ceanothus species we have tested, Mason's ceanothus is not well adapted to basic soils, and survived for only about 2 years under irrigation when soil pH was 7.5 to 8.2.

This species was successfully established and plants made satisfactory growth at the 5000 foot (1524 m) elevation Vista Grande plot. Plantings were grown in paper pots from stem cuttings treated with growth hormone to stimulate rooting. Nearly half have survived and grown to be 1 foot (30 cm) high and 5 feet (1.5 m) wide over a 6-year period. However, similar plantings at Nixon (3500 feet, 1067 m), and Wolfskill (2600 feet, 792 m) plots were not successful. Only a few plants survived for more than a year or two and these grew very slowly, spreading to no more than 3 feet (0.9 m) across during the same 6-year period.

Until more is known about the adaptability of Mason's ceanothus, plantings should probably be limited to elevations above 4000 feet (1220 m) or on moister sites elsewhere.

Promising, But Not Fully Tested

There are other species that, based on limited tests, are potentially valuable for some situations. Included are two semiprostrate native species—sweet sagebrush (*Artemisia ludoviciana* var. *incompta*) and Newberry's penstemon (*Penstemon newberryi*) from Utah and California, respectively—and a semiprostrate to somewhat erect plant, silver or swamp saltbush from Western Australia. These two species have effectively stabilized raw banks and road cuts in plantings made at a number of higher elevation sites in California, Idaho, and Utah. Silver saltbush is good forage; it grows rapidly and spreads aggressively by stem layers, thus providing cover for raw, disturbed areas. We believe these species merit additional study to determine their suitability and adaptability to different southern California conditions.



Figure 12—Sweet sagebrush is a native, low-growing, deciduous semishrub suited mostly to higher elevations. It spreads primarily by abundant root sprouts and occasionally by stem layers formed along the prostrate branches.

Sweet sagebrush (*Artemisia ludoviciana* Nutt. var. *incompta* [Nutt.] Keck).—Sweet sagebrush is a low-growing, aromatic plant native to Utah and surrounding area, usually on calcareous soils at 5000 to 9000 feet (1524 to 2743 m) elevations. It forms dense mats, generally less than a foot (30 cm) high, with individual plants up to 6 feet (1.8 m) across the crowns. Although the tops die back each winter, plants grow rapidly and aggressively from root sprouts as well as from occasional stem layers (fig. 12). It was one of the most satisfactory plants tested for stabilizing and protecting logging road cut fill slopes in southern Idaho.⁷ There are nodules on the roots and probably endotropic mycorrhizae as well, and both may add nitrogen to the soil (Farnsworth and Clawson 1972).

Plantings made at Nixon and Vista Grande plots had good survival and plants averaged over 1 foot (30 cm) diameter after the first season. Gophers, unfortunately, damaged or destroyed about one-third of our test plants by nipping off the succulent roots below the crown. Plants do not appear to be affected adversely by grazing animals or other pests in other

areas where this species has been grown.

Direct seedings have not been made because sweet sagebrush seed has not been available. However, plants were readily propagated from root sections and rooted from stem cuttings kept under intermittent mist. A single plant grown in the nursery can produce enough root stock sections for 100 or more plants in a single year. Root masses obtained during late winter from either native or nursery-grown plants and placed in flats in a heated greenhouse usually develop new shoots within 2 to 3 weeks. The root sections with attached stem can be transplanted into propagating pots for later use, or directly to field sites. This plant is probably best suited for plantings at higher elevations, generally above 5000 feet (1524 m) in mountain areas in the West. It should be useful around such mountain communities as Idyllwild, Lake Arrowhead, or elsewhere, if native conifers do well.

Newberry's penstemon (*Penstemon newberryi* A. Gray).—Newberry's penstemon or mountain pride, native in the Cascade range and Sierra Nevada in California and adjoining states, is an attractive, mostly evergreen plant with dense foliage 6 to 12 inches (15 to 30 cm), or sometimes to 18 inches (45 cm) tall. It spreads by means of stem layers along the

⁷Monsen, S. B. 1973. Personal communication. Intermountain Forest and Range Exp. Stn., Boise, Idaho.

semierect branches. It occurs at elevations of 4500 to 10,000 feet (1372 to 3048 m), mostly on neutral to moderately acid soils formed from granitic or in some instances volcanic materials. Its ability to reproduce vegetatively makes the plant useful in many places. The conspicuous crimson blossoms in late spring and early summer add to its attractiveness. It has done exceptionally well when planted on cut and fill slopes in the central Sierra Nevada in tests made by the Department of Environmental Horticulture, University of California, Davis (pers. commun., A. T. Leiser 1973). The plant has done poorly, most plants dying within a year, when grown in the Riverside, California, nursery on soils with pH 7.5 to 8.0. This fact suggests it is not well adapted to basic soils and perhaps not to lower elevations. Until more is known, plantings could well be restricted to soils that are moderately acid to neutral, pH 5.5 to 7.5.

No direct seedings have been attempted because seed of this penstemon has not been available. Presumably the seed will require cold stratification (Everett 1957) or other treatment to germinate satisfactorily.

Tip cuttings taken in the fall or early winter and kept under intermittent mist are readily rooted. The rooted cuttings, preferably held in pots, or "wildling"

plants formed naturally from stem layers, can be transplanted while the ground is still moist in early spring. This shrub deserves additional study so that we can determine its range of adaptability and learn how to produce stands from direct seedings.

Silver or swamp saltbush (*Atriplex rhagodioides*)—

Silver saltbush, introduced into this country from Australia about 5 years ago, has grown satisfactorily in the nursery at Riverside and at two field test sites near Malibu, Los Angeles County, and Laguna Beach, Orange County, California. This plant is a very palatable "ice cream" forage plant in its homeland. It is dioecious; it usually grows rapidly to 3 or 4 feet (0.9 or 1.2 m) tall, and spreads considerably wider. New plants are formed along the decumbent branches (fig. 13). Foliage is dense. Like most other saltbushes, it has a high mineral content, usually over 10 percent, and maintains higher levels of fuel moisture throughout the greater part of the year than most chaparral species. It is not tolerant to frost. Test plantings of this species grew satisfactorily during the first season at the Nixon plot but none survived the following winter when minimum temperatures dropped to about 20° F (-7° C). The plant seems suited to about the same climatic range where Australian saltbush



Figure 13—Silver or swamp saltbush, introduced from Australia, grows rapidly. Plants are 3 to 4 feet tall and spread much wider as the decumbent branches layer readily upon the ground. It is regarded as an "ice cream" forage plant in its homeland; the foliage has a relatively high mineral content and thus could help to slow down the spread of wildfires.

(*A. semibaccata*) has been naturalized, generally below 2000 feet (610 m) elevation in California.

Plants at the Riverside nursery produced seed which cutting tests showed to have less than 25 percent fill during the second year. The seed ripens in late August to early September, but persists on the plant so it can be collected for a few weeks. It germinates readily without special treatment, or plants can be propagated from tip cuttings under intermittent mist. It can probably also be established by transplanting "wildlings" formed naturally from stem layers. Sufficient seed has not been available for direct seeding tests.

The plant has dense foliage, high mineral content, aggressive spreading habits, and high palatability, suggesting that fuel or forage volume can be regulated to a large extent by grazing animals. We believe silver saltbush has good potential for planting to reduce fire hazards, as well as to improve habitat for grazing animals where it may be adapted in California.

Taller Shrubs

Most tall shrubs were eliminated because of excessive fuel volume, but three shrubs—fourwing saltbush, allscale saltbush, and purple rockrose—were tested extensively because of desirable characteristics.

Fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.)—Fourwing saltbush is widely distributed on dry plains and hillsides throughout much of the Western United States and Mexico. It is common in the desert and semidesert areas of southern California from near the coast to inland elevations up to 7000 feet (234 m). It grows on a variety of soils where pH ranges from 6.0 to 7.4 or higher. It is both drought tolerant and relatively cold tolerant. It is excellent browse for livestock and big game and habitat for upland game birds, and a good choice for stabilizing roadsides and other disturbed sites within its range.

Depending on the site, fourwing saltbush grows 2 to 6 feet (0.6 to 1.8 m) tall, and to 10 feet (3 m) across the crown, but some semiprostrate ecotypes exist. It establishes a deep and widely spreading root system that makes it drought resistant, and also desirable for stabilizing disturbed soils. It may also be important in soil fertility because nitrogen-fixing endotrophic mycorrhizae occur on the roots (Williams and others 1974).

The foliage of fourwing saltbush has from 10 to 15 percent mineral content, it is low in fat or volatile oil (table 4), and moisture content of small green twigs

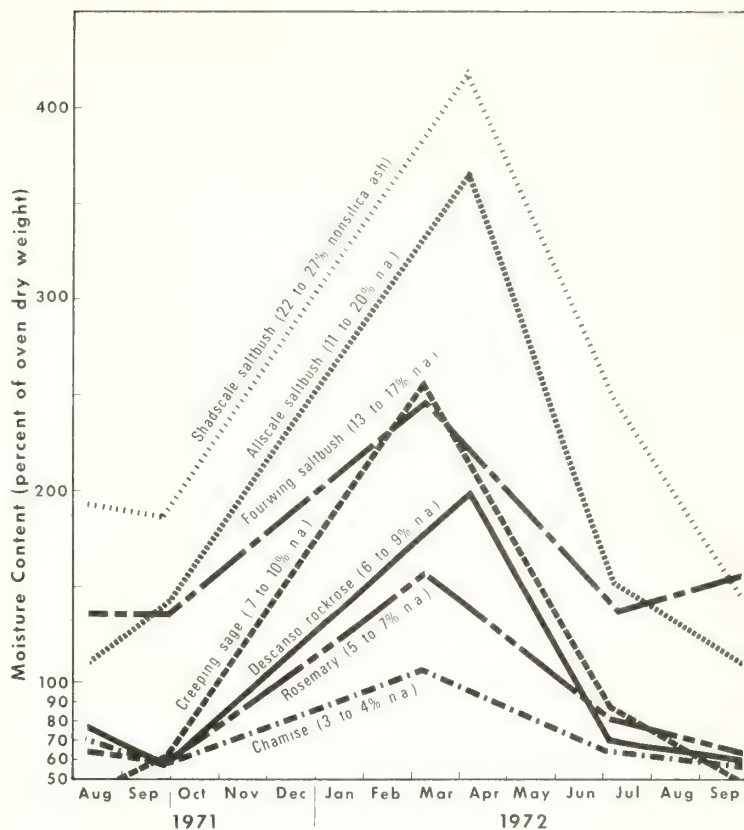
rarely drops below 100 percent (fig. 14). These characteristics make it less flammable than most chaparral plants. We have observed singed or partially burned plants following wildfire in southern California when other vegetation was more nearly consumed, and young regrowth, along roadsides was scarcely affected by the wildfires. The plant will burn, however, if dry fuel accumulates during drought or as a stand matures and becomes decadent. The plants generally sprout profusely from lower stems following burns, browsing, or mowing. Management should provide for this periodically, to maintain a healthy, fire-resistant stand.

Fourwing saltbush can be readily established by direct seeding or from potted transplants. The best time for planting in southern California is in late winter or early spring, usually late January to mid-March depending on elevation and exposure. Warm moist soil in the seed zone is essential for both germination and seedling establishment (Nord and others 1971). Seed should be sown about 1/2 inch (1.3 cm) deep except that up to 1 inch (2.5 cm) depth may sometimes be advisable to reach moist soil. Best stands can be expected from plantings made on well prepared, firm seedbeds where competition from other plants has been removed just prior to or simultaneous with seeding. Soil above the planted seed should be firmed with press wheels, a cultipacker or, when broadcast as on steep roadsides and other disturbed places, with a drag-chain or harrow. During the first year, plants may grow to be 1 to 2 feet (30 to 60 cm) tall and almost as wide with a root system up to 6 feet (1.8 m) deep and 10 feet (3 m) in diameter.

Seeding of 2 to 4 pounds dewinged seed per acre (2.2 to 4.5 kg/ha) is usually sufficient; however, up to 8 pounds per acre (9 kg/ha) may be necessary to establish a satisfactory stand upon disturbed roadside areas. The seed is generally available from some commercial seed dealers and costs between \$2 to \$5 per pound (\$4.40 to \$11.00 per kg) for dewinged seed. Seed should be from a nearby source or be grown in a climate similar to that of the site being seeded unless other tested strains are known to have similar or better adaptation.

Major deterrents to achieving good seeded stands are the susceptibility of small seedlings to frost and damping-off, removal of planted seed by rodents, and clipping and destruction of young plants by small animals—mostly rabbits. Deferring plantings until as late in the season as possible will generally minimize losses from frost or damping-off. Coating seed with a repellent may help to cut down losses by rodents;

Figure 14—Seasonal fuel moisture content of foliage—leaves and current year's stem leaders—of seven native and introduced shrub species was recorded at Nixon test plot, North Mountain Experimental Area, Riverside County, California, from August 1971 to late September 1972. Plants were generally 3 to 6 years old and growing along rows at widely spaced intervals with light competition from annual plants. Range in percent of nonsilica ash content is shown for each species.



however, no practical means have been found that will effectively fend off rabbits from small plantings other than to fence the planted areas with small-mesh netting, such as 1-inch (2.5-cm) poultry wire, so that these animals cannot get through. Putting out grain treated with 1080 and strychnine poison or spraying plants with a repellent coating is only temporarily helpful (Plummer and others 1970). The saltbush plants after the first year are not nearly as susceptible to rabbits as the young seedlings.

Fourwing saltbush plants are 3 to 4 years old before they produce significant amounts of seed, but thereafter abundant crops are borne during most years. The fruit can be collected as it ripens from October to December by flailing it into large boxes or onto drop cloths spread beneath the plants, or by vacuum seed harvesters developed for this purpose (Plummer and others 1968). Dewinging the seed by running it through a hammermill equipped with sieve openings of 1/4 inch (0.6 cm) diameter improves germination and permits planting by conventional drills. The number per pound varies from 18,000 to 34,000 (40 to 75/g) for winged seed and after dewinging from 28,000 to 60,000 (62 to 132 g), of which about one-half have embryos (Springfield 1970). No

special treatment, other than dewinging, is necessary for this seed. Seed viability is maintained for several years when seed is kept in cloth containers at room temperature (Franclet and Le Houérou and others 1971; Plummer and others 1970; Springfield 1970).

Plantings of fourwing saltbush intended to help stop fire spread should be of sufficient size and density so they can slow down or dampen fire burning from adjoining chaparral. Solid bands, at least 25 feet (7.6 m) wide, could best serve this purpose if placed adjoining the native brush and buffered along the other edge with low-growing plants such as creeping sage. Annual grazing either by sheep or cattle, or mowing the plants at 3- to 4-year intervals would prevent accumulations of dead material and allow the saltbush to be most effective in reducing fire hazards.

Allscale saltbush (*Atriplex polycarpa* [Torr.] Wats.)—Allscale saltbush, also known as desert saltbush, cow-spinach and cow-lettuce, is native to desert and semidesert areas from California to Utah and south into Mexico. It is locally abundant throughout its range on slightly acid (pH 6.5) to strongly saline soils (pH about 8.0). Best development is on deep, well drained soil, and because of this, much of the

area it formerly occupied has been reclaimed for irrigated agriculture. It grows to a crown height and width of about 5 feet (1.5 m), although 3 feet (0.9 m) tall is more common. Its branching is intricate, frequently spiny, and small.

It is somewhat less cold tolerant than fourwing saltbush—its upper elevation is about 5000 feet (1524 m)—but is more drought hardy, often surviving with only 4 to 5 inches (10 to 13 cm) of fall and winter precipitation. The foliage is rated fair to good for domestic livestock (*fig. 15*), good for deer, and the plants provide excellent cover for quail. The plants sprout profusely from lower stems following mowing or clipping. Thus, this species has potential to produce fodder as an agronomic crop on marginal irrigated lands subject to prolonged drought and excessive salinity (Goodin and McKell 1970). The harvested fodder is a good source of protein but is low in fat and carbohydrates. The foliage has a high non-silica ash content ranging from 11 to 20 percent according to the season (*table 4*), and it effectively retains high levels of fuel moisture, usually over 100 percent throughout the year.

Allscale, in many respects, is similar to fourwing saltbush in ease of establishment and seed production but is more restricted in its adaptability. It could best be used at elevations below 3500 feet (1067 m) in southern California plantings. The seed does not require scarification; it germinates rapidly and usually within a few days under warm moist conditions.

Plants may grow to be 1 foot (30 cm) or taller, with a root system up to 4½ feet (1.4 m) deep and twice as wide during the first year. Most plants are dioecious and will bear fruit beginning the second year.

The seed maintains high viability for at least 5 years and probably longer if it is stored in porous containers such as cloth bags that will permit air exchange when stored at room temperatures. The seed has lost practically all viability within a few months when held at room temperature in tightly sealed containers, including plastic bags. However, if seed is stored in a refrigerator or deep freeze, it can and should be kept in a tightly sealed container.

Allscale saltbush seed is commercially available from some seed dealers and costs up to about \$5 per pound (\$11.00 per kg). To purchase it, however, prior arrangements should be made with a dealer in native plant seeds who may have to locate and collect it in the field.

Purple rockrose (*Cistus villosus* L.)—Purple rockrose is an upstanding, moderately dense evergreen shrub generally 2 to 4 feet (0.6 to 1.2 m) tall with rounded crowns 2 to 4 feet (0.6 to 1.2 m) in diameter. The foliage is dark green and slightly aromatic. During late spring and summer, plants bear showy lavender flowers. This plant is hardy and well adapted to many soils and other conditions from near the coast to 5000 feet (1524 m) or higher elevations in southern California. It is admirably suited and has



Figure 15—Several saltbush species provide palatable and nutritious browse for livestock and big game, and outstanding cover and nesting for upland game birds. This native stand of allscale or desert saltbush in San Bernardino County, California, provides a substantial portion of the forage used by sheep bands, especially during the late spring and early summer.

been planted extensively for erosion control and to some extent for landscaping (Juhren 1972). Plantings established 15 to 20 years ago in southern California have persisted, but plants stagnate beginning in 8 to 12 years and thereafter, dead fuel begins to accumulate (pers. commun., Kenneth R. Montgomery).

The foliage of purple rockrose contains from 5 to 9 percent ash (table 4), and it is relatively low in fat and volatile oils as compared to most other *Cistus* species (pers. commun., Kenneth R. Montgomery). Moisture content of the foliage generally drops below 70 percent during the late summer and fall.

When grown under favorable conditions on brush-cleared wildland sites, purple rockrose produces seed within 2 years. The seed ripens in late summer to early fall, and generally is held on the plants for several weeks after it matures. Thereafter, seedheads or capsules can be stripped or plucked off the plants into containers and seed can be separated and cleaned from this material by threshers, scarifiers, hammer-mills, and fanning mills. It is possible for a good worker to collect a pound (0.45 kg) or more of this seed per hour from plants bearing good seed crops. This seed is commercially available and currently costs about \$35 per pound (\$77 per kg).

There are about 525,000 seed per pound or 1150 per gram. Seed is partially dormant but several treatments will improve and hasten germination. The test results which follow were not directly comparable because the seed was from different sources and probably differed in viability:

	<i>Germination</i> (percent)	<i>Peak of average germination</i> (days)
Treated seed:		
Boiling water (1 min) ¹	92	6 to 10
Dry heat (80° C, 2 min) ¹	93	7 to 12
Gibberellic acid (200 p/m, 2 hr) ²	69	8
Controlled seed:		
Boiling water (1 min)	19	17 to 21
Dry heat (80° C, 2 min)	23	3
Gibberellic acid (200 p/m, 2 hr)	37	12

¹ Los Angeles County and State Arboretum, Arcadia (Pers. commun., Kenneth R. Montgomery).

² Forest Fire Laboratory, Riverside. Tests using other concentrations and soaking periods with gibberellic acid are still in progress.

³ Data not available.

We are not aware of any direct seedings of purple rockrose on wildland sites that have resulted in more than a sparse stand. Volunteer seedlings often survive in substantial numbers, however, in association with existing parent stands. This can occur after fire and on disturbed ground without the effect of fire. The potential to direct seed this species, therefore, would appear to be fairly good (pers. commun., Kenneth R. Montgomery).

Potted transplants such as are carried by some commercial nurseries have shown good survival and grown satisfactorily at several places in southern California. Plantings in 2 by 2 by 8 inch (5 by 5 by 20 cm) bands at Wolfskill, Nixon, and Vista Grande (table 2) had in most instances 70 percent or higher survival, and plants were growing satisfactorily 8 years after they were planted on two out of three sites. Survival and growth recorded during the first 4 years at these sites are as follows:

	<i>Wolfskill</i>	<i>Nixon</i>	<i>Vista Grande</i>
Elevation (feet)	2500	3500	5000
Survival (percent):			
First year	90	86	98
Second year	90	84	94
Fourth year	20	72	80
Plant growth, height by crown diameter (inches):			
First year	8 by 11	12 by 15	11 by 8
Second year	12 by 14	21 by 18	17 by 20
Fourth year	14 by 16	32 by 35	16 by 38

High mortality that occurred between the second and fourth year at Wolfskill and dieback of the plant tops in some years at Vista Grande indicate that this *Cistus* is not well adapted to either the drier conditions or colder temperatures that are found on some sites within the chaparral zone in southern California. Most of the plants injured by frost recovered to a large extent, however. Except for moderate clipping of young plants by deer, mostly during the first year, the species is not greatly affected by grazing or other destructive agents.

The primary use of purple rockrose should be for plantings on disturbed sites such as road cut and fill slopes to protect the soil and to reduce encroachment of flash fuels, and for landscaping.

APPENDIX

A. The Vegetation Around Structures

There is less open, unpopulated wildland, and more urban and urban-rural land with each passing year. Fire management around homes becomes less a matter of wildland strategy and more one of protecting homes built in the brushland or forest.

Much of the protection for a home should be "built in" by planners and builders. The County Supervisors Association of California (1965), in cooperation with forest fire protection agencies, suggest such things as (1) street names and numbers, (2) safe ingress and egress for personnel and equipment, (3) fire protection water facilities, (4) spacing of buildings, (5) clearance between brush or other vegetative growth and structures, and (6) community firebreaks.

For the owner of a home in brushland, management of the vegetation on and around his property is one of the best means to reduce loss during wildfire. This requires attention to landscape design, to type and species of plants to allow or encourage, to "fuel sanitation," and to irrigation of plants near the home.

The first step in vegetation management for fire safety has been outlined by State and county ordinances. These require removal of all flammable vegetation within 30 feet (9.1 m) of a structure. Single trees, shrub specimens, and ground covers are allowed if they will not transmit fire to the building. State or local authorities may require this zone be widened if the 30-foot (9.1-m) clearing is not sufficient. Clearing brush to 100 feet (30 m) or more from the downhill side of a building might be required to prevent radiation from igniting the building during wildfire, for example.

Fuel sanitation requires that dead and low-growing branches be pruned from trees and shrubs. Ground covers may also require pruning, particularly on dry sites; otherwise, fire will burn through them, although not with the same intensity as through native brushfields. Dry needles, leaves, and other debris must not be allowed to accumulate in quantity. Such materials will ignite from firebrands, burn intensely, and carry fire into brush or tree crowns. Fire spreads more rapidly in dry grass than in brush, and tall dense grass can support intense fire. Grass stands should be grazed or mowed.

Moisture content is generally considered the most important factor affecting flammability. Unirrigated woody plant growth contains its highest moisture content during the early spring, then gradually de-

clines to a low, frequently flammable level. Moisture content or irrigated brush in the San Bernardino Mountains also declined but not to the hazardous low levels in unirrigated chaparral (Youngner and others 1972). Unwatered landscaping is nearly always a fire hazard during the summer and fall. Watered and pruned landscape plants can provide some protection against fire.

Some plants burn more readily than others, so a knowledgeable homeowner will minimize planting of the obviously flammable species, and seek out plants that are less flammable.

Trees

The conifers as a group are more flammable than "broadleaved" deciduous trees. Coniferous trees include the pine (*Pinus*), deodar (*Cedrus*), cypress (*Cypressus*), cedar or juniper (*Juniperus*), incense-cedar (*Libocedrus*), and other cone-bearing trees. Broadleaved trees and shrubs are represented by oaks (*Quercus*), willows (*Salix*), maples (*Acer*), and many others. The conifers are more flammable because they contain materials such as resins and terpenes which burn readily, whereas most broadleaved species do not, or not as much. Also, moisture content of the coniferous foliage tends to be lower than that of deciduous trees. The difference in flammability is great enough that firebreaks of deciduous trees and shrubs have been recommended for coniferous forests (Fedrunnov 1952). However, Maire and Stoutemyer (1962) reported, following the Bel Air fire of November 1961, that many conifers around homes had not burned, even though they were killed.

Conifers will continue to be used as ornamentals because of their beauty, stateliness, and adaptation to our climate. They can be used with relative safety if they are irrigated, if dry needles are not allowed to accumulate on or beneath them, and they are used as specimen trees and not in plantations around the home. Species adapted to brushland zone conditions include:

Deodar (*Cedrus deodara* Loud.).

Cypress (*Cypressus* L.). Arizona cypress (*C. glabra* Sudw.), Forbes cypress (*C. forbesi* Jepson), Italian cypress (*C. sempervirens* L.), and Monterey cypress (*C. macrocarpa* Hartw.) are all used in landscaping.

Pines (*Pinus* L.). Monterey pine (*P. radiata* D.

Don.), Aleppo pine (*P. halepensis* Mill.), Canary Island pine (*P. canariensis* C. Smith.), Italian stone pine (*P. pinea* L.), Japanese black pine (*P. thunbergi* Parl.), Coulter pine (*P. coulteri* D. Don.), and Knobcone pine (*P. attenuata* Lemm.) include most choices for lower elevation planting.

Canary Island pine possesses the ability to generate new shoots (branches) along the main trunk, if fire kills existing branches. It shares this ability with very few other conifers, but some broadleaved tree species, coast live oak (*Quercus agrifolia* Nee.) for example.

Juniper or cedar (*Juniperus* L.). California juniper (*J. californica* Carr.) and Utah juniper (*J. utahensis* Engelm.) are well suited to hot areas.

Like the conifers, eucalypts are apt to be flammable, and for similar reasons—the high content of volatile oils in their leaves, and absence of high moisture content or minerals that might counteract the effect of the oils (King and Vines 1969). Some species slough bark, and build up considerable volumes of ground litter. Blue gum (*Eucalyptus globulus* Labill.) is notorious for all these faults and should be avoided in landscape plantings. Fire has spread in the litter beneath rows of blue gum, as well as through the crowns.

Some attractive medium-sized eucalypts (30 to 70 feet, 9 to 21 m) that endure a variety of low elevation climatic conditions and are less “messy” than others are red box gum or red box eucalyptus (*E. polyanthemus* Schau.), red ironbark or ironbark eucalyptus (*E. sideroxylon* Cunn.), and desert gum (*E. rudis* Endl.). Other eucalypts are planted as park, roadside, or specimen trees. Creek or red gum (*E. rostrata* Schlecht.) is often favored where a tree 100 feet (30 m) tall is acceptable.

Most broadleaved trees are acceptable for landscaping provided they are adapted to the area, are irrigated, and pruned. Brazilian pepper tree (*Schinus terebinthifolius* Raddi.), Peruvian or California pepper tree (*Schinus molle* L.) were reported to withstand fire well during the Bel Air and other southern California fires. Numerous other broadleaved trees are acceptable for California landscaping, and can be suggested by nurserymen.

Shrubs

All native shrubs will burn under extremely low soil moisture and relative humidity, and high wind-spread and air temperature, particularly if the stand is mature with 20 percent or more of the fuel dead. However, a few native shrubs are observed to be more flammable than the majority, and some less so. Lab-

oratory testing has also shown differences in flammability among shrub species (King and Vines 1969; Ching and Stewart 1962) but reasons are not always obvious.

Chamise (*Adenostoma fasciculatum* H. & A.) usually tops lists of native plants objectionable because of flammability. It is our most abundant shrub, making up perhaps 70 percent of the chaparral in southern California, and 60 percent statewide (Leonard and Carlson 1957). It has physical characteristics that contribute to a rapid rate of energy release (Countryman and Philpot 1970) and 8.5 to 12 percent of the leaves and small stems were “ether extractives”—waxes, oils, terpenes, and fats—that contain about twice the heat content of the extracted fuel, and which play an important role in fire spread (Philpot 1969). Chamise burns with a black oily smoke that has earned it a second common name, “greasewood.” Obviously, chamise should not be allowed in quantity close to structures.

California buckwheat inhabits lower mountain slopes and flats. Because it grows well on dry disturbed sites, it is planted along highways, and sometimes as a landscaping plant around homes. But because of a profusion of dry flower stalks, fine stems, shreddy bark, and low summer fuel moisture, mature stands of California buckwheat are quite flammable. This plant and the associated species have supported intense fires.

Other members of the coastal sage plant community are frequently very flammable. Plants such as California sagebrush (*Artemisia californica* Less.), white sage (*Salvia apiana* Jeps.), black sage (*S. mellifera* Greene.), and goldenbush (*Ilaplopappus* Cass.) drop leaves or die back during drought periods. The volume of dead twigs and ground litter frequently exceeds the live green. Such should be cleared from around structures.

Not native but potentially hazardous in a fire situation are bamboos and rosemary. Bamboo in dry situations drops lots of leaves, and these burn readily. Rosemary is an attractive, drought-enduring ground cover shrub which burns very readily. We have seen rows of it in wildland nursery plantings burn completely when less flammable species—purple rockrose and fourwing saltbush—of the same age on either side did not burn.

There are numerous native shrubs that may be left as specimen plants during brush clearing operations, or planted for the same purpose. They are generally less useful close to the home, however, than many nursery-produced varieties because they are hard to grow under irrigation. They need well drained soil

and are killed with frequent yard watering.

Three sumacs (*Rhus*) are acceptable. Sugarbush sumac (*R. ovata* Wats.), lemonadeberry (*R. integrifolia* [Nutt.] Benth. & Hook.), and laurel sumac (*R. laurina* Nutt. in T. & G.) are all attractive shrubs with stiff leathery leaves. Two wild cherries—Catalina cherry (*Prunus lyonii* [Eastw.] Sarg.) and Hollyleaf cherry (*P. ilicifolia* [Nutt.] Walp.) may be used. Toyon or Christmas-berry (*Heteromeles arbutifolia* M. Roem.) is another good choice. California coffeeberry (*Rhamnus californica* Ech.) is tolerant of moisture and attractive as well. Bush poppy (*Dendromecon rigida* Benth.) produces an abundance of bright yellow flowers which add to its attractiveness. Manzanitas (*Arctostaphylos* Adans.) and scrub oak (*Quercus dumosa* Nutt.) produce considerable litter and probably burn a little more readily than the other choices mentioned.

Several reports have come to the authors' attention of shrubs and ground cover from the plant genus *Myoporum* not being consumed during wildfire. These are not native to California, but are among the many useful plants nurserymen have available for home landscaping.

Several shrubs tested for low flammability on wild-

land sites are also useful for landscaping near the home. Several of the saltbushes can be used on dry or moist well-drained sites. Purple and Descanso rockrose will survive on dry rocky sites where it is difficult to establish other shrubs. Gum rockrose is more flammable and should not be used for this purpose.

Ground Covers

Many ground covers are satisfactory for home landscaping if they are irrigated and maintained relatively free of dead material. Montgomery and Stallings (1970) from Los Angeles County list 30 that will provide excellent fire protection if planted in a wide circle around structures. This listing was updated and enlarged in 1973 (Montgomery 1973). The Los Angeles Times (1969) published "A guide to ground covers" which lists or describes more than 40. Another source of information is Williamson (1973).

If ground is level or only gently sloping, any of the ground covers can be used. However if terrain is steeply sloping, deep-rooted low-growing woody species such as dwarf coyote brush, prostrate ceanothus, or low-growing saltbushes do the best job of holding the soil in place.

B. Index of Common and Scientific Names of Species

Grasses

Annual ryegrass *Lolium multiflorum* Lam.
Blando brome (softchess) *Bromus mollis* L.
Buffelgrass *Pennisetum ciliare* (L.) Link
Fountaingrass *Pennisetum setaceum* (Forsk.) Chiov.
Hardinggrass *Phalaris tuberosa* L. var. *stenoptera* (Hack.) Hitchc.
Intermediate wheatgrass *Agropyron intermedium* (Host) Beauv.
Perennial veldtgrass *Ehrharta calycina* Sm.
Pubescent wheatgrass *Agropyron trichophorum* (Link) Richt.
Sandhill grass *Brachiaria ciliatissima* (Buckl.) Chase
Sherman big bluegrass *Poa ampla* Merr.
Smilgrass *Oryzopsis miliacea* (L.) Benth.
Tall wheatgrass *Agropyron elongatum* (Host) Beauv.

Shrubs

Allscale saltbush *Atriplex polycarpa* (Torr.) Wats.
Australian saltbush *Atriplex semibaccata* R. Br.
Black sage *Salvia mellifera* Greene.

Bush poppy *Dendromecon rigida* Benth.
California buckwheat *Eriogonum fasciculatum* Benth.
California coffeeberry *Rhamnus californica* Esch.
California sagebrush *Artemisia californica* Less.
Castlevalley saltbush *Atriplex cuneata* A. Nels.
Catalina cherry *Prunus lyonii* (Eastw.) Sarg.
Caucasian artemisia *Artemisia caucasica* Willd.
Chamise *Adenostoma fasciculatum* H. & A.
Creeping or Sonoma sage *Salvia sonomensis* Greene.
Deerweed *Lotus scoparius* (Nutt. in T. & G.) Ottley
Descanso rockrose *Cistus crispus* L.
Dwarf baccharis or dwarf coyote brush *Baccharis pilularis* DC.
Fourwing saltbush *Atriplex canescens* (Pursh) Nutt.
Gardner's saltbush *Atriplex gardneri* (Moq.) D. Dietr.
Goldenbush *Haplopappus* Cass.
Gray lavendercotton *Santolina chamaecyparissus* L.
Green galenia *Galenia pubescens* (Eckl. & Zeyh.) Druce (1917)
Green lavendercotton *Santolina virens*
Gum rockrose *Cistus ladaniferus* L.
Hollyleaf cherry *Prunus ilicifolia* (Nutt.) Walp

- Trees**
- Aleppo pine *Pinus halepensis* Mill.
Arizona cypress *Cupressus glabra* Sudw.
Blue gum *Eucalyptus globulus* Labill.

Aleppo pine *Pinus halepensis* Mill.
 Arizona cypress *Cupressus glabra* Sudw.
 Blue gum *Eucalyptus globulus* Labill.

- Brazilian pepper tree *Schinus terebinthifolius* Raddi
California juniper *Juniperus californica* Carr.
Canary Island pine *Pinus canariensis* C. Smith.
Carob *Ceratonia siliqua* L.
Cedar or juniper *Juniperus* L.
Coast live oak *Quercus agrifolia* Nee.
Coulter pine *Pinus coulteri* D. Don.
Creek or red gum *Eucalyptus rostrata* Schlecht.
Cypress *Cupressus* L.
Deodar *Cedrus deodara* Loud.
Desert gum *Eucalyptus rudis* Endl.
Forbes cypress *Cupressus forebsi* Jepson
Incense-cedar *Libocedrus* Endl.
Italian cypress *Cupressus sempervirens* L.
Italian stone pine *Pinus pinea* L.
Japanese black pine *Pinus thunbergi* Parl.
Knobcone pine *Pinus attenuata* Lemm.
Maples *Acer* L.
Monterey cypress *Cupressus macrocarpa* Hartw.
Monterey pine *Pinus radiata* D. Don.
Oaks *Quercus* L.
Peruvian or California pepper tree . *Schinus molle* L.
Pines *Pinus* L.
Red box gum or red box eucalyptus ... *Eucalyptus polyanthemos* Schau.
Red ironbark or ironbark eucalyptus ... *Eucalyptus sideroxylon* Cunn.
Utah juniper *Juniperus utahensis* Engelm.
Willows *Salix* L.

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The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Nord, Eamor C., and Lisle R. Green.

1977. **Low-volume and slow-burning vegetation for planting on clearings in California chaparral.** USDA Forest Serv. Res. Paper PSW-124, 41 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Vegetation that is low-growing and either low in volume, slow burning, or both, is needed for reduction of fire hazard on fuelbreaks and other brush-cleared areas in California. Of over 50 shrub species and many grass species that were test planted, about 20 shrubs and an equal number of grasses were chosen for plot and field trials. Creeping sage, a few saltbushes, and a few grasses—mostly perennials—are adapted within the wide range of chaparral site conditions, and were successfully established by direct seedings as well as by other cultural methods on these sites. Shrub test results are tabulated and characteristics of each of the more promising species are described, with attention to usefulness for planting; techniques for collecting or treating seed to improve germination and for propagating plants; and methods for establishing these plants on wildland sites.

Oxford: 432.17-018

Retrieval Terms: fire-resistant plants; fuel modification; fuelbreaks; fire hazard reduction; vegetation establishment.

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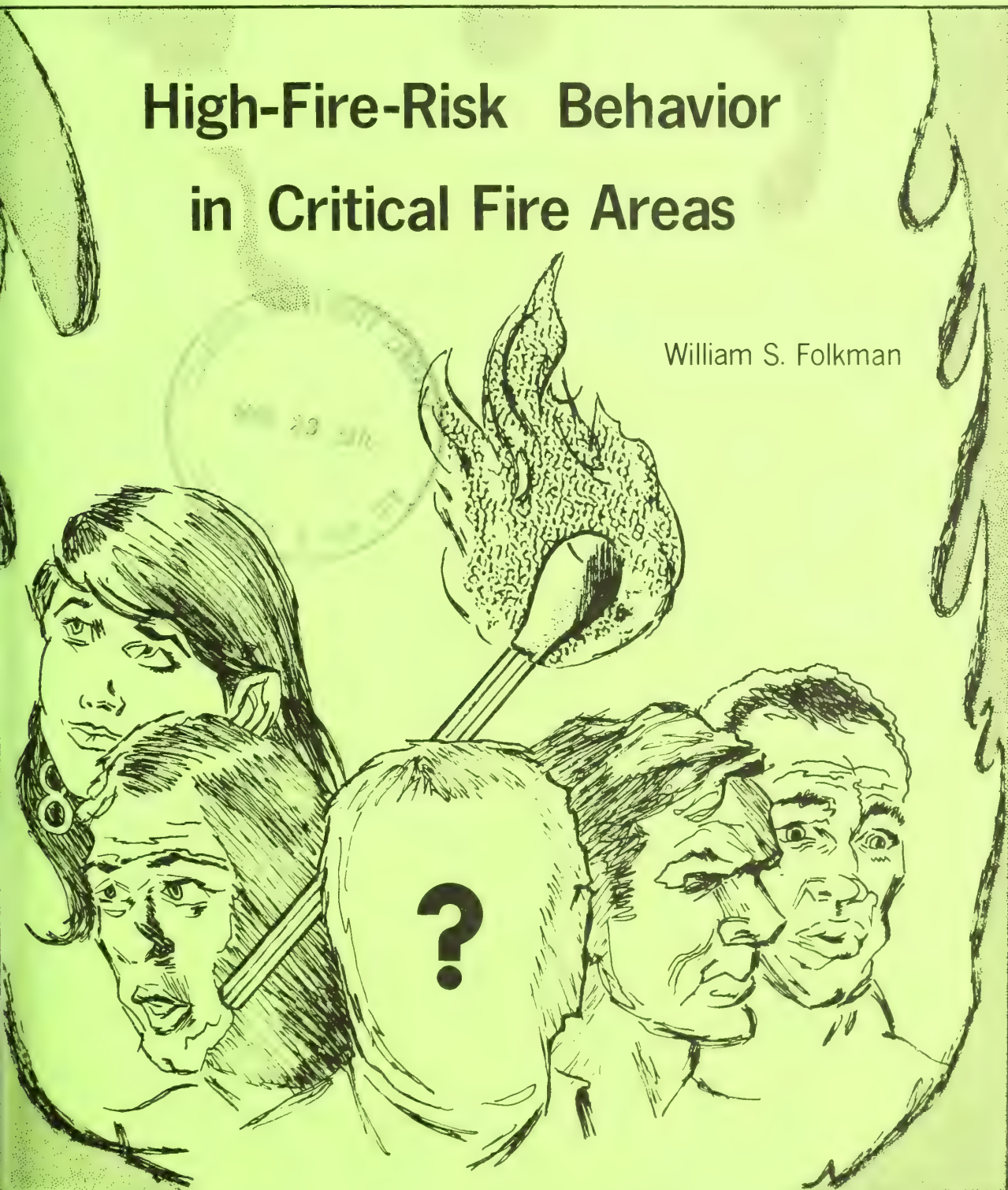
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PACIFIC SOUTHWEST Forest and Range Experiment Station

High-Fire-Risk Behavior in Critical Fire Areas

William S. Folkman



CONTENTS

Page

Summary	1
Introduction	3
Methods	3
Related Research	3
Study Area	4
Interviewing Procedure and Sample	4
Results	6
Discussion	8
Literature Cited	9
Appendix	10

The Author

WILLIAM S. FOLKMAN is responsible for the Station's research on sociological problems in the prevention of man-caused forest fires, with headquarters in Berkeley, Calif. He holds a bachelor's degree in agriculture from Utah State Agricultural College, a master's degree in sociology from the University of Utah, and a doctorate in rural sociology from Cornell University. He joined the Station staff in 1962.

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This study was undertaken as part of an ongoing program of research into the problem of man-caused forest fires supported jointly by the Pacific Southwest Forest and Range Experiment Station and the California Department of Forestry. We are grateful for the assistance of the following persons: Gene Bernardi, formerly research sociologist with the Experiment Station, who prepared the study plan; Charles E. Starnes and Stephan Graham, Sociology Department, University of California, Riverside, who, with their staff of observer/interviewers, collected the data; and the staff of the San Bernardino National Forest, whose aid in selection of the study areas and in making arrangements for the team of interviewers was very helpful.

SUMMARY

Folkman, William S.

1977. **High-fire-risk behavior in critical fire areas.** USDA Forest Serv.
Res. Paper PSW-125, 12 p., illus. Pacific Southwest Forest and
Range Exp. Stn., Berkeley, Calif.

Oxford: 431.3(794)—U301.153.

Retrieval Terms: fire prevention; user characteristics; public attitude;
campfires; fire misuse; high-risk-fire behavior.

Little is definitely known about people who start forest fires. To date, the systematic research identifying high-risk people has been on the basis of indirect indicators—attitudes, knowledge, and frequent activity in wildlands. This study focuses on observation of actual behavior with fire in a wildland situation. The study was conducted within the San Bernardino National Forest in southern California, which has had a high incidence of man-caused fires. Observation/interviews were conducted in three types of areas: wilderness, established campground, and built-up commercial and residential areas. Interviews were attempted in every instance in which fire-related behavior was observed. The populations sampled in the three types of areas proved so diverse that it was not possible to combine them for statistical analysis as originally planned. The types of fire behavior observed also differed markedly from one area to another, as did the proportions of proper and improper use of fire.

The limited size and quality of the distinctly different samples from the three areas, and our inability to combine them, affected the results of our analysis. Few consistent differences appeared in comparisons between persons using fire and those not using it. When the comparison was between those using fire properly and those misusing it, the differences were

even fewer and less consistent. Differences in fire-related behavior were found to be associated more with differences in the activities typical of the different areas studied than with differences in personal characteristics.

Part of the problem may be attributed to the fact that each person was observed only for a very limited time. Consequently, chance frequently determined classification of behavior as safe or unsafe fire use.

Analysis on the basis of the indirect criteria (attitude and knowledge indicators) was equally inconclusive—supporting the conclusion that the difficulty was with the size of sample and the disparate characteristics of the populations studied.

It would not be appropriate, solely on the basis of this study, to say that persons who engage in fire-risk behavior differ in measurable ways from those who do not. This study does make it quite apparent, however, that all types of persons may behave in an unsafe manner under certain circumstances, although possibly some may represent a higher risk than others.

Also, the purpose for which a person is in the wildland has an important bearing on the amount and nature of the fire activity he will engage in, and consequently, on the fire risk he is apt to represent.

We know very little about the people who start forest fires. Although by their aggregate numbers and their cumulative damage they do create a critical problem in California, they are seldom apprehended or positively identified. We have no assurance that the few who do get caught are at all typical of the thousands who escape detection.

To date, the systematic research identifying people likely to show high-risk behavior has dealt with indirect indicators—that is, surveys have determined attitudes and knowledge related to fire-safe procedures for hazardous wildland areas. Those determined to have little knowledge of proper fire prevention procedures, or a poor attitude toward the subject, or both, are assumed to represent high risks. Although it seems logical to assume that there would be a strong correspondence between attitude and actual behavior, or between knowledge of what is proper and the actual performance of it, studies in other subject matter areas have shown that the relationship may be very weak or in some circumstances even reversed (Alwin 1973, DeFries and Ford 1969, Warner and DeFleur 1969, and Wicker 1969).

Because our previous attempts to identify the high

fire-risk types of people were thus inconclusive, this study was designed to focus on observation of actual behavior with fire. High-fire-risk behaving persons are seen as those whose use of fire is potentially dangerous, given the existing environment or situation. They were identified by a study team who went into a wildland critical fire area of southern California. There they observed and interviewed persons using fire or fire-hazardous equipment while in an occupational, recreational, or residential role. Through observation, the team identified those who engaged in appropriate and cautious behavior and those who did not. Then through interviews they obtained demographic, motivational, and other information designed to determine whether those who are fire cautious differ from those who are not, and if so, in what ways.

Southern California was chosen as a study area because the fires of disastrous proportions that occur at too-frequent intervals there have focused attention on the wildland fire problem. In selecting a particular National Forest, we considered the incidence of fires from smoking and campfires—leading sources of fires in California's National Forests.

METHODS

Related Research

Although the assumption is often made that fire use is related to individual characteristics, very few studies have attempted to directly identify the characteristics of persons who are, or have been, careless in their wildland fire behavior. Christiansen and Folkman (1971) studied records of adults apprehended after they had actually ignited forest fires, presumably unintentionally. Siegelman and Folkman (1971) studied apprehended youthful fire setters. The subjects in these two studies were selected from fire investigation reports; because data from this source were incomplete, and for other reasons, the samples were not representative. Consequently, these were exploratory studies, seeking hypotheses to be systematically tested at some future time.

The characterization of 165 fire starters presented by Christiansen and Folkman (1971) was tested systematically by the research reported here. Among the characteristics they noted are that most fire starters are employees working in the forest, few are housewives or professionals, a majority come from small towns, most have good reputations, and most em-

ployers held responsible for forest fires started by their employees are private employers in the railroad-ing, lumbering, or utilities industries.

The Butte County Survey (Folkman 1965) identified persons as high fire risks by their low scores on questionnaire items on fire prevention attitude and knowledge, as associated with high levels of wildland activities. These high-fire-risk persons tended to be young (under 25 years of age), unmarried, and with a limited amount of schooling for their age. A later survey (Folkman 1975) found that people 65 years of age, or older, who also have limited education and income but are frequent wildland visitors, are also a target group for attention in fire prevention work, on the basis of their attitude and knowledge scores. These findings also bear testing in wildland settings by observation of persons who actually engage in fire-risk behavior.

Some work has been done on behavior patterns possibly related to fire risk, such as littering and depreciative behavior in forest campgrounds.

Public Opinion Surveys, Inc. (1968) interviewed two nation-wide samples of adults in which the re-

spondents were asked to indicate whether, during the preceding month, they had littered in any of eight listed ways. Reported littering among adults 21 to 35 was found to be more than three times greater than among persons over 50, and nearly twice that for adults 35 to 49; men litter more than women; farmers and residents of the smallest communities (those under 2500) are more likely to litter than residents in the biggest cities.

McCool and Merriam (1970), found, in a Boundary Water's Canoe Area Study, that place of residence, group membership, and occupation affected sensitivity to litter and compliance with littering regulations. Groups from the local area were least sensitive to litter and complied least with littering regulations; organized groups (Boy Scouts, church groups) more frequently carried out their nonburnable trash than did nonorganized groups. Regulation compliance was greatest among managers, professionals, and students, and least among craftsmen, salesworkers, and operatives. McCool and Merriam also report that compliance was greatest when the communication on litter was conveyed with least anonymity.

Clark and others (1971), through systematic participant observation, recorded depreciative behavior in forest campgrounds. They found no strong relationship between age of camper and incidence of depreciative acts, although age groups differed in the types of acts committed. Teenagers most often violated campground rules (which included littering and traffic violations) and were less likely than adults or children to commit nuisance acts (excessive noise, unsupervised children, intentionally freed pets). Children were most likely to commit acts of vandalism.

Many studies have attempted to determine the characteristics of outdoor recreationists. Differences have been found in the characteristics of persons enjoying different forms of outdoor recreation (Sofranko and Nolan 1970) or different camping styles (Burch 1970; Burch and Wenger 1967; Hendee and others 1968; and West and others 1969). Also, characteristics of visitors to one public park do not necessarily match those of visitors to another (King 1965; Shafter 1965). Similarly, it is conceivable that how persons who are high fire risks differ from those who are not may depend upon the circumstances in which they find themselves.

Although these findings are helpful for comparative purposes, we must guard against assuming beforehand *either* that the high-fire-risk persons will have characteristics similar to the majority, *or* that they will represent an atypical minority.

Study Area

The study was conducted within the San Bernardino National Forest in southern California, which had the highest man-caused fire severity ratio, for the period 1963-72, of any U.S. National Forest.¹ The San Bernardino averaged 26 campfire associated fires per year during the 3-year period 1970-72, a considerable increase from the 5.1 fires per year from this cause in the previous decade. An average 20.5 fires per year were attributed to smoking.

Three types of areas within the Forest were selected for observation and interviews. One was within the San Geronio Wilderness Area; another was the developed campgrounds bordering the Wilderness, and the third was the built-up commercial and residential area about Big Bear Lake, about 25 miles from the campgrounds.

Interviewing Procedure and Sample

The method chosen was to observe fire-related behavior unobtrusively at the time of the first encounter with a given person or group of people. Consequently, the observer had no apparent influence on the observed behavior. Contact between groups in the wildland setting was limited, so that interviewing a member of one group did not affect later contact with other groups.

Observers judged fire use to be "proper" or "improper" on the basis of whether or not such use conformed to, or violated, some well-recognized fire-safety rule or regulation. Smoking while hiking and failure to clear to mineral soil to a 5-foot radius about a campfire are examples of improper fire use.

Interviews were attempted in every instance in which fire-related behavior was observed. If the incident involved more than one person, the observer mentally numbered each person in the group and selected one at random to interview. To maintain the independence of the sample, only one person per group was interviewed. Whenever there were no fire users available, other persons, not involved in any fire-related behavior, were generally interviewed. In the diffusely populated Wilderness Area, however, an interview was attempted with a member of every group encountered. No individuals or groups were interviewed more than once in the course of the study.

¹ DeBruin, Henry W. *Man-caused fire activity severity analysis*. Memorandum, May 29, 1973, on file, Forest Service, U.S. Department of Agriculture, Washington, D.C.

Some bias may have been introduced by the pattern of sampling. The San Geronio Wilderness Area and the campgrounds were very busy on weekends, but had relatively little use during the rest of the week. After a preliminary sortie, the study team decided to limit interviews in the Wilderness Area to weekends, as it was not worthwhile to backpack into the area for only a few interviews. Also, in the Wilderness Area, interviews were conducted along two major trails, which according to Forest Service figures, were used by about 65 percent of the visitors. It is possible that more experienced backpackers would tend to use the less frequented trails. Another source of bias may have been the reservation system in use. Reservations were often made weeks in advance. Those who appeared without advance reservations were shunted off into less frequently used trails, or to some other wilderness area. Thus, in our sample, there would tend to be over representation of the most "organized" users—possibly middle-class employed people, accustomed to using reservation systems. Nevertheless, the characteristics of our sample correspond closely to those of other studies of wilderness users (Burch and Wenger 1967; Hendee and others 1968).

In the campgrounds, our sample was more consistent and complete. An interview was attempted with a member of each group in which there was an observed instance of proper or improper fire behavior. The only major segment of campground users not fully represented were those who had trailers or campers, with no outside fires. Interviews were completed with over 80 percent of those observed to be engaged in fire-related behavior.

The sampling problem was most difficult in the built-up areas around Big Bear Lake. The interviewers had to work harder to persuade people to be interviewed, and there was a higher refusal rate. Almost the only fire-related behavior observed was smoking, as people moved about the streets and entered or left stores or automobiles. Those interviewed tended to be older, or to a lesser extent younger, than the average person encountered. Middle-aged people tended to be more hurried or busy, and we got more rejections from them. Because interviewers used the "wildland area" criteria in defining improper fire-related behavior, they observed few instances of im-

proper fire use in these built-up areas. If careless or unaware types of actions, which would be dangerous under more hazardous conditions, had been noted, more observations might have been made. But this procedure would require estimating the extent to which fire-risk behavior would be modified in more hazardous surroundings.

The characteristics of the persons interviewed vary so widely between the three samples that it is apparent that the samples represent three quite distinct populations (*Appendix, table 2*). Consequently, we have maintained their identity in the analysis, rather than combining them as originally planned.

Because of the limited size of the unaggregated samples and other inadequacies in the data, statistical tests of significance of differences were only used for heuristic purposes.

Respondents encountered in the wilderness, in contrast to those from the other two areas, tended to be young single males. Over half of them were currently enrolled in school, but still, on the average, they had completed more years of schooling than had those encountered in the other areas. Few were in nonwork status (retiree, housewife). This sample showed the highest proportion of persons employed in professional and technical jobs, but also the highest proportion of laborers. Their average total family income was noticeably higher than that of the other respondents.

In most characteristics, the respondents from the commercial/residential area represented the antithesis of respondents in the wilderness, with the campground users falling between these two groups. The sample of campground users did show the highest proportion of married and nonwhite respondents; although, even in this group, less than one in ten were in the latter category. It also showed the highest proportion of persons employed full time.

In summary, the sample obtained in the campgrounds is satisfactory; it fairly represents the population using this type of forest facility. The sample from the Wilderness Area is perhaps less representative of *all* users of the San Geronio Wilderness Area, but fairly represents those users of the most frequented portions of the Wilderness. Unfortunately, however, the sample from the commercial/residential area is little more than a sample of opportunity.

RESULTS

The samples from the three areas differed markedly from one another in the proportion of persons observed using fire properly and improperly, as follows:

	<i>Percent of persons observed</i>			
	<i>Commercial/ residential area (n=157)</i>	<i>Camp- ground (n=269)</i>	<i>Wilderness (n=122)</i>	<i>All areas (n=548)</i>
Fire use:				
Proper	73.9	65.4	53.3	65.1
Improper	2.5	32.7	18.8	21.0
None				
observed	23.6	1.9	27.9	13.9
Total	100.0	100.0	100.0	100.0

The samples differed not only in proportions of proper and improper fire use, but also in the types of fire behavior observed (*table 1*; note that *table 1* includes a few reports of two or more fire activities by a single individual, percentages in the tabulation by persons observed cannot be derived directly by summing from *table 1*).

In the commercial/residential area, where smoking was the major activity observed, most such behavior was not considered risky under the circumstances. A faulty spark arrester on a motorbike was the only other fire risk observed in this area. In the campgrounds, activity related to campfires was the most prevalent fire-risk behavior noted, and smoking was next in rank. Equipment misuse was also observed. Very few wilderness users were observed using smoking materials, partly, perhaps because of the high fire hazard, but also because persons encountered in the wilderness area proved less apt to be smokers than those in other wildland situations—only 25.4 percent for wilderness as opposed to 80.9 and 42.8 percent for commercial/residential and campground areas. The most frequently observed fire activity in the wilderness area was equipment use (pack stove); campfire use was next.

On the basis of observations and interviews, comparisons were made between persons who misused fire and those who used it properly, and between those who used fire in any form and those who did not use fire at all. The comparisons related fire use to socio-economic variables: age, sex, race, employment status, place of employment and residence, years of school completed, marital status, and family income. Variables describing amount or kind of wildland use were also evaluated: number of visits to wildland

areas, frequency of camping, use of portable stove, outdoor campfires, etc. Types of outdoor recreation engaged in, number and average number of members of group, and composition of group (i.e., immediate family, other relatives, fellow workers, friends, etc.) were also considered.

Some differences in characteristics appeared in comparisons between persons using fire and those not using it. When the comparison was between those using fire properly and those misusing it, fewer differences appeared.

In summary, persons using fire in the commercial/residential area tended to be younger, single, local wildland residents, employed in sales, operative, or service occupations. In the wilderness area, those using fire were most frequently married and not currently employed. In the campgrounds, they were more likely to be out of school and in occupations other than professional, technical, or laborer categories. Number of persons in the party appeared to be related to fire use in the campground and wilderness areas. Nonfire-users tended to be in parties somewhat larger than the median in campgrounds and slightly smaller than the median in the wilderness area.

No differentiation was possible between fire users and non-users in relation to the variables of race, working in a wildland area, number of visits to a wildland area, composition of the person's group, school grade completed, employment (self-employed or working for others), type of business or industry, and family income, in any of the three areas studied.

Few of the distinguishing characteristics that were evident in the user-nonuser comparisons appeared in comparison between those who used fire in a safe manner and those who used it in a way that was identified as risky. For the commercial/residential area, type of outdoor recreation preferred was different; those who used fire properly expressed a preference for camping and fishing, but those who used fire improperly opted for hiking, motorcycling, or just relaxing. Those who showed "risky" fire behavior in this area were equally divided among the young and those 65 years of age or over. Those who were widowed, divorced, or separated were more frequently observed to engage in fire-risky behavior; the fire-safe persons were most frequently found to be married.

In the campgrounds, the only variable that stood out was smoking. A greater proportion of those who used fire in a risky fashion proved to be smokers.

None of the variables considered was effective in

Table 1—*Proper and improper fire use observed in three areas of the San Bernardino National Forest, California, 1975*

Fire activity	Frequency of observation in . . .		
	Commercial/ residential area (n=157)	Campground (n=269)	Wilderness (n=122)
	Percent		
Smoking:			
Proper			
Smoked in 3 ft cleared area	59.9	11.2	4.1
Crushed smoke on mineral soil	8.9	1.5	.8
Broke match	—	.4	—
Other	1.3	2.6	—
Improper			
Smoked while hiking	1.3	—	—
Smoked while standing or sitting in uncleared area	—	7.1	1.6
Smoked in inadequately cleared area	.6	1.9	1.6
Discarded smoking materials in uncleared area	—	.7	—
No smoking reported	28.0	74.7	91.8
	100.0	100.0	100.0
Campfire:			
Proper			
In cleared circle, 10 ft	1.3	36.1	16.4
Left fire dead out	—	6.7	—
Other	—	—	5.7
Improper			
In cleared circle, less than 10 ft	—	7.8	1.6
Site not clear to bare soil	—	12.6	4.1
Made fire under overhead foliage	—	—	.8
Left fire unattended	—	1.1	—
Other	—	—	—
No campfire reported	98.7	35.7	71.4
	100.0	100.0	100.0
Debris burning:			
Proper—in cleared circle, 10 ft	—	.7	—
No debris burning reported	100.0	99.3	100.0
	100.0	100.0	100.0
Playing with fire:			
Proper—cleared area: activity ok	—	1.1	—
Improper—uncleared or prohibited area	—	.4	1.6
No playing with fire reported	100.0	98.5	98.4
	100.0	100.0	100.0
Equipment use:			
Proper			
10 ft clearance to bare earth	.6	16.7	36.9
Spark arrester ok	3.2	1.1	—
Improper			
Inadequate clearance or none	—	4.1	10.6
Faulty spark arrester or none	.6	—	—
No equipment use reported	95.5	78.1	52.5
	100.0	100.0	100.0

distinguishing proper from improper fire users in the wilderness area.

Although some differences were observed between persons who used fire (whether safely or unsafely), and those who did not use fire in any form, these differences were seldom consistent from one subpopulation to another. The few differences observed in

the comparison between fire-risk persons and fire-safe persons did not support the various sub-hypotheses proposed in this study. Therefore, the general hypothesis being tested—persons who engage in fire-risk behavior differ in measurable ways from persons who do not engage in fire-risk behavior—must be considered as unsupported on the basis of this study.

DISCUSSION

This study was undertaken with considerable trepidation. We were attempting for the first time to make meaningful observations of fire-risk behavior under wildland conditions. The failure to find distinctive differences between people observed in unsafe fire behavior and those not so observed was, of course, contrary to our expectations. The possibility that there is really no difference between the two groups has powerful implications for fire prevention planning and would require rethinking of research and application strategies. All of our previous experience has led to the understanding that some people, for various reasons, represent a higher fire risk than do others. Alternatively, therefore, we must question the adequacy of the study.

The size of the three subsamples, which we could not combine for analysis, was limited. The division on the basis of location (commercial/residential, campground, or wilderness) with further division on the basis of risk, meant that some categories contained only a few respondents.

Of necessity, the determinations made by our staff were random—only that fire-related activity observable at time of encounter was evaluated as fire safe or risky. A representative sample of fire users should thus have been assured. However, although all those persons observed engaged in unsafe fire behavior were properly placed in the fire risk category, many persons placed in the fire safe category may be there because at the time of encounter they did not happen to be behaving carelessly. Thus, there is a large element of chance in their classification as fire safe individuals. There is no assurance that further observation would not have revealed unsafe fire behavior. Similarly, differentiation between persons observed in fire-related behavior, as opposed to those not so observed, depends largely on chance.

Because of the inconclusive results of the observational analysis, an attempt also was made to differentiate high and low fire risk on the basis of the indirect

criteria used in previous studies (i.e., knowledge, attitude, and activity scores), but the results were equally inconclusive. A few variables showed up as being related to risk, but the relation was inconsistent between samples. This inconsistency supports the conclusion that the size and adequacy of sample and the disparate characteristics of the populations studied are responsible for the inconclusive findings. Although we cannot conclude that persons who show fire-risk behavior differ in measurable ways from those who do not, neither can we assume the opposite. Further research profiting from the experience of this study is needed to ferret out the subtle and complex factors related to fire-risk behavior. Such research might well take the form of detailed study of fire related behavior in high-risk situations, perhaps by participant observation. Findings would form the basis for hypotheses to be tested on a broader scale, giving particular attention to the difficult problems of rigorous sampling in such circumstances.

One point which this study does make quite plain, and one that needs to be made repeatedly, is that all types of persons may behave in an unsafe manner under certain circumstances. In our attempts to delineate high fire-risk "types," we are apt to forget that these delineations—like all predictions of human behavior—are based on probabilities. Some people may represent a higher risk than others, but everyone is a potential source of uncontrolled fire.

Another point to be stressed is that persons in the wildland for different purposes—camping in an established compound, backpacking, or whatever—are apt to differ quite markedly in the nature of the fire risk they represent. Such variations must be considered by fire management agencies who wish to influence behavioral changes of wildland users.

Although it is still desirable to identify those types of persons who, for whatever reason, are a higher fire risk than others, we must also recognize that we are *all* potential risks—in truth, the enemy is us.

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APPENDIX

Table 2—Selected social and demographic characteristics of persons observed during study of fire-related behavior, by observation area, San Bernardino National Forest, 1975

Characteristics	Commercial/ residential area (n=157)	Campground (n=269)	Wilderness (n=122)	Total (n=549)
	Percent			
Age:				
Under 20	17.9	9.0	24.6	15.1
20-24	8.3	15.0	24.6	15.3
25-29	15.4	15.4	9.0	14.0
30-44	21.8	36.8	31.1	31.2
45-64	25.6	20.7	10.7	19.8
65 and over	10.9	3.0	—	4.6
Total	100.0	100.0	100.0	100.0
Median years	35.8	32.5	25.0	32.1
Sex:				
Male	61.1	73.6	82.8	72.1
Female	38.9	26.4	16.4	27.7
Not reported	—	—	.8	.2
Total	100.0	100.0	100.0	100.0
Race:				
Chicano	1.9	5.9	—	3.5
White	97.5	91.8	96.7	94.5
Black	.6	1.1	1.6	1.1
Other	—	1.1	.8	.7
Not reported	—	—	.8	.2
Total	100.0	100.0	100.0	100.0
Marital Status:				
Married	52.2	75.1	46.7	62.2
Widowed, divorced or separated	14.0	8.6	4.9	9.3
Single	32.5	16.0	48.4	27.9
Not reported	1.2	.4	—	.6
Total	100.0	100.0	100.0	100.0
Schooling completed:				
0-4 years	—	—	—	—
5-7 years	.6	.7	.8	.7
8 years	5.1	1.5	2.5	2.7
Some high school	21.7	11.2	12.3	14.4
High school graduate	26.1	27.1	11.5	23.4
Some college	35.0	35.7	35.2	35.4
College graduate	5.7	12.6	18.0	11.9
Post-graduate	5.7	10.4	19.7	11.1
Not reported	—	.7	—	.4
Total	100.0	100.0	100.0	100.0
Currently enrolled in school:				
Yes	24.8	31.2	51.6	33.9
No	75.2	68.0	48.4	65.7
Not reported	—	.7	—	.4
Total	100.0	100.0	100.0	100.0

Table 2—Selected social and demographic characteristics of persons observed during study of fire-related behavior, by observation area, San Bernardino National Forest, 1975—Continued

Characteristics	Commercial/ residential area (n=157)	Campground (n=269)	Wilderness (n=122)	Total (n=549)
<i>Percent</i>				
Employment status:				
Employed, full time	46.5	66.5	53.3	57.8
Employed, part time	17.8	11.5	35.2	18.6
Unemployed	1.9	1.5	1.6	1.6
Retired	14.0	4.8	—	6.4
Student	7.6	8.2	9.0	8.2
Housewife	10.2	7.4	.8	6.8
Other	1.9	—	—	.5
Not reported	—	—	—	—
Total	100.0	100.0	100.0	100.0
Type of business:				
Agriculture, forestry, and fisheries	4.5	3.0	2.5	3.3
Mining	—	—	—	—
Construction	8.3	8.6	5.7	7.8
Manufacturing	14.0	17.5	13.9	15.7
Transportation, communications, and other public utilities	6.4	9.7	9.0	8.6
Wholesale and retail trade	18.5	10.0	11.5	12.8
Finance, insurance, and real estate	4.5	4.1	4.1	4.2
Business and repair services	4.5	3.7	1.6	3.5
Personal services	6.4	1.9	5.7	4.0
Entertainment and recreation services	6.4	2.6	3.3	3.8
Professional and related services	15.3	22.7	35.2	23.4
Public administration	5.1	6.7	4.1	5.7
Not reported	1.9	1.5	—	1.3
Does not apply	4.5	8.2	3.3	6.8
Total	100.0	100.0	100.0	100.0
Kind of work:				
Professional, technical, and kindred workers	16.6	22.3	37.7	24.1
Farmers and farm managers	—	.4	.8	.4
Managers, officials, and proprietors, except farm	5.1	8.6	5.7	6.9
Clerical and kindred workers	12.1	11.9	9.8	11.5
Sales workers	10.8	5.9	4.1	6.9
Craftsmen, foremen, and kindred workers	12.1	21.6	13.9	17.2
Operatives and kindred workers	12.1	10.4	4.1	9.5
Service workers	15.3	4.8	8.2	8.6
Laborers	8.3	3.0	10.7	6.2
Not reported or does not apply	7.6	11.2	4.9	8.8
Total	100.0	100.0	100.0	100.0

Table 2—Selected social and demographic characteristics of persons observed during study of fire-related behavior, by observation area, San Bernardino National Forest, 1975—Continued

Characteristics	Commercial/ residential area (n=157)	Campground (n=269)	Wilderness (n=122)	Total (n=549)
Family income (dollars):				
Under 1,500	2.5	—	.8	.9
1,500-2,999	1.9	1.5	.8	1.5
3,000-4,499	5.7	2.6	4.1	3.8
4,500-5,999	5.1	2.2	3.3	3.3
6,000-7,999	10.8	5.9	—	6.0
8,000-9,999	5.7	5.9	5.7	5.8
10,000-14,999	26.1	28.6	26.2	27.4
15,000-19,999	13.4	24.2	23.0	20.8
20,000 and more	14.0	20.4	33.6	21.5
Not reported	14.6	8.6	2.5	8.9
Total	100.0	100.0	100.0	100.0
Median	\$9,829	\$12,304	\$14,194	\$11,915
Residence:				
City	28.6	55.4	59.0	48.9
Suburb	8.8	30.3	30.3	24.4
Rural	8.8	10.9	9.8	10.1
Wildland	53.7	3.4	.8	16.6
Total	100.0	100.0	100.0	100.0



Folkman, William S.

1977. **High-fire-risk behavior in critical fire areas.** USDA Forest Serv. Res. Paper PSW-125, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Observations of fire-related behavior of wildland visitors were made in three types of areas—wilderness, established campground, and built-up commercial and residential areas—within the San Bernardino National Forest, California. Interviews were conducted with all persons so observed. Types of fire-related behavior differed markedly from one area to another, as did the proportions of observed proper and improper use of fire. Persons who misused fire could not be distinguished from those who did not, when interview data were analyzed in relation to selected social and demographic characteristics. Small sample size and wide individual variation suggest why results were inconclusive.

Oxford: 431.3(794)—U301.153.

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Oxford: 431.3(794) U301.153.

Retrieval Terms: fire prevention; user characteristics; public attitude; campfires; fire misuse; high-risk-fire behavior.

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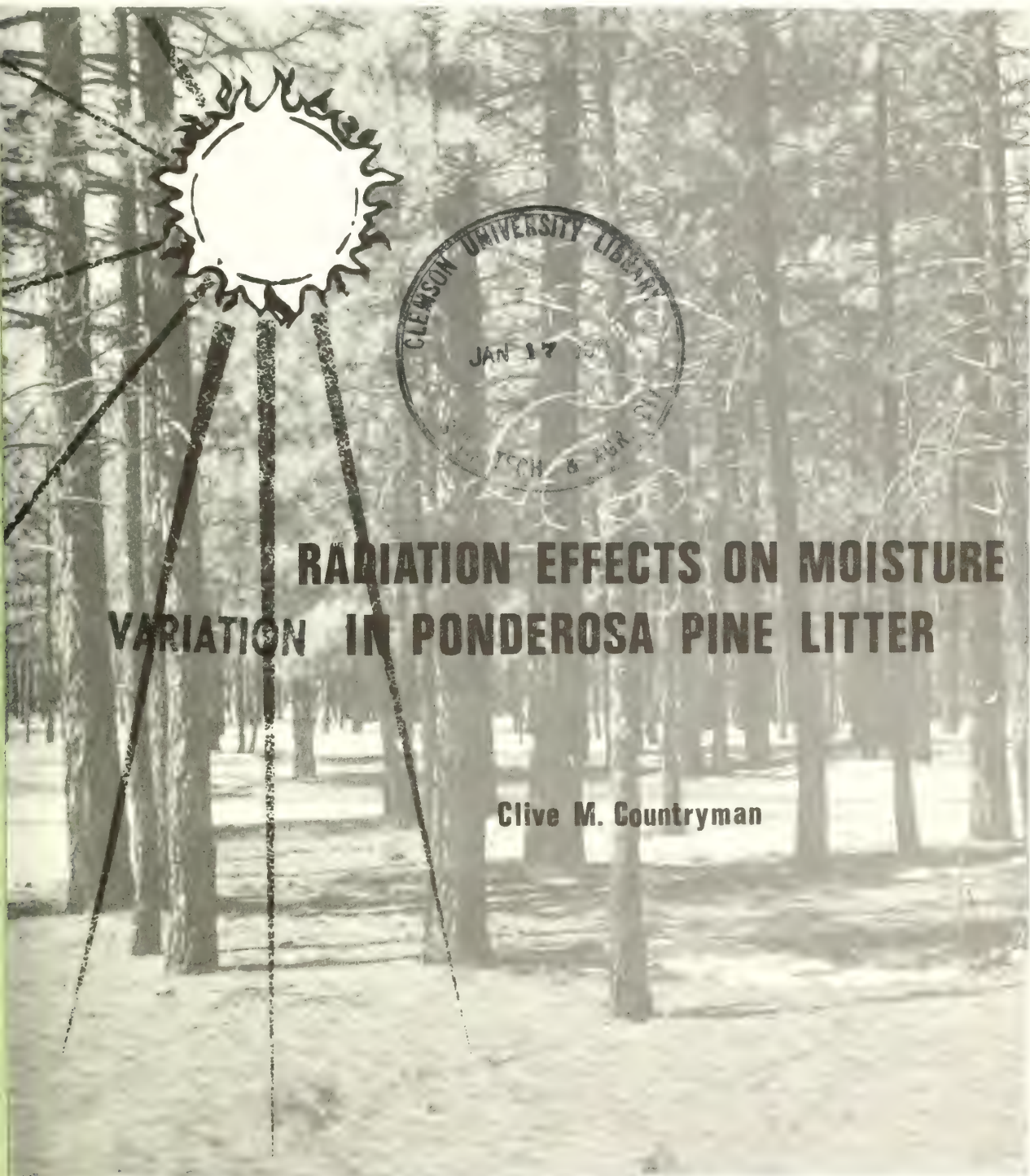
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PACIFIC SOUTHWEST Forest and Range Experiment Station

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RADIATION EFFECTS ON MOISTURE VARIATION IN PONDEROSA PINE LITTER

Clive M. Countryman

CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Study Area	3
Procedures	4
Transect Descriptions	4
Environmental Conditions	5
Results and Discussion	5
Solar Radiation Effects	7
Radiation Cooling Effects	13
Transect Moisture Variations	16
Conclusions	22
Literature Cited	23

The Author

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The original study was designed and conducted by Charles C. Buck, former Assistant Director, Division of Forest Fire and Atmospheric Sciences Research, Forest Service, U.S. Department of Agriculture, Washington, D.C., and now deceased.

SUMMARY

Countryman, Clive M.

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Oxford: 431.2:114.351 — 174.7 *Pinus ponderosa*.

Retrieval Terms: *Pinus ponderosa*; surface fuels; litter; fuel moisture content; solar radiation.

Reliable estimates of the moisture in wildland fuel are essential for research investigations of fire behavior, and in firefighting, fire use, fire danger rating, and other activities concerned with the ignition and behavior of wildland fire. Although research has ascertained many of the factors controlling the moisture content of wildland fuels and has provided some understanding of the manner in which fuel moisture affects fire, there is relatively little information about the variation in the moisture content of wildland fuels as they exist in place. This study explored the variation in moisture of litter under ponderosa pine (*Pinus ponderosa* Laws.) timber stands.

The study revealed that moisture variations of sufficient magnitude to affect the ignition and behavior of fire can occur within short horizontal distances. These variations were found to be caused primarily by solar radiation reaching some litter areas through openings in the crown canopy, and cooling of the litter directly under the openings at night. Analysis of the data indicates that a close relationship exists between the maximum solar radiation received and the litter moisture. The lower moisture of litter that is exposed to solar radiation and then shaded will persist through the day. Consequently, the history of the

exposure of an area of litter to radiation is more important in determining its moisture content at any given time than are the conditions at that time. Because of the strong dependence of litter moisture on radiation effects, any influence affecting the radiation received or lost, such as stand characteristics, time of day and year, latitude, atmospheric conditions, and topographic configuration, will also affect the moisture variation patterns in the litter.

Because of the exploratory nature of the study, the specific results probably apply directly only to the study area. However, the strong relationships found between litter moisture and radiation have important and widespread implications. Other vegetative types also provide only partial protection of surface litter from solar radiation and nighttime radiation losses, and therefore large variation in the moisture of surface fuels are likely in these types too. The results of the study indicate a need for more sophisticated investigations of radiation heating and cooling in various wildland fuel types and situations, with the object of developing area classification systems and measurement techniques permitting realistic estimates of fuel moisture.

The strong influence of fuel moisture on the behavior of wildland fire is well known. Fuel moisture has long been of major import in the prediction of fire behavior for fire control and fire use applications. And as sophisticated fire prediction models requiring detailed fuel moisture data as inputs come into more extensive practical use, information on the variations in fuel moisture assumes even greater consequence.

Extensive research has provided some understanding of the manner in which fuel moisture affects fire behavior, and has ascertained many of the factors controlling the moisture in wildland fuels. However, most investigations of fuel moisture variations have been concerned with changes at a specific point as affected by weather, season of the year, or fuel characteristics, and with wide-ranging effects of altitude, slope, and aspect. There is virtually no knowledge of the spatial variation in the moisture of surface fuels that are intermittently exposed to solar radiation and partially shielded from radiation cooling. Such fuels are an important part of the fuel complex in most wildland fuel types.

During a study of the rate of fire spread in ponderosa pine litter in northern California (Curry and Fons 1938), it was observed that the moisture content of the surface layer of pine needles varied widely over the experimental area.

Because fire spread is greatly affected by moisture in this fuel, the observation led to an investigation of the moisture content of the surface litter¹ as it changed during the day, the season, and from place to place. Although the study was exploratory, and conducted nearly a half-century ago, when wildland fire research was still in its infancy, the results provide one of the few observations of the actual variation in the moisture content of the fuel type.

The study was conducted primarily as an aid in fuel moisture sampling and evaluation for the rate-of-spread study, and the results were not published. Recent analysis of the data, however, has revealed that in addition to valuable information on in-place variation of fuel moisture, the study also provides much information on the magnitude of the effects of variations in incoming shortwave solar radiation and outgoing longwave radiation on the moisture content of intermittently exposed and shaded surface fuels. Consequently, the results of the study have much wider application and implications in fire control, fire use, and fuel moisture research than originally anticipated. This report describes the study and the results of the analysis.

STUDY AREA

The study area chosen is at a latitude of 41° 21' N., near the foot of the eastern slopes of Mt. Shasta in north-central California. The study site was level and at an elevation of about 4000 feet. The soil is a sandy loam derived from pumice and lava ash.

The climate of the area is characterized by hot, dry summers and cold winters. Much of the precipitation comes in the form of snow, and snow cover often persists throughout the winter. Occa-

sional thunderstorms occur during the summer, and dry foehn winds frequently appear in the fall. A considerable amount of needle fall occurs each year in the pine stands, but because of the cold winters and dry summers, the pine litter decays slowly. The litter is kept compact by the heavy snowfall.

¹The term "litter" as used in this paper refers to all organic material above mineral soil.

PROCEDURES

Six transects, each 150 feet long, were laid out in ponderosa pine stands of various ages and densities in the spring of 1936. Stakes set at 5-foot intervals along the transects marked the 30 "sampling stations" from which samples of the pine litter were taken for moisture determination. Samples weighing 60 to 70 grams were collected from an area 5 feet in diameter around the stakes. Only surface needles to a depth of two or three needles were collected, and the needles were replenished from surrounding areas at the end of each sampling period to maintain the litter depth. The moisture content of the samples, on a dry weight basis, was determined by the then newly developed xylene reflux distillation method (Buck and Hughes 1939).

For most sampling periods the litter samples were collected as rapidly as possible — usually 10 to 15 minutes were required to complete the sampling of a transect. For Transect 3 on September 22, however, a different sampling technique was used. This time the stations were sampled successively 15 minutes apart, beginning with Station 1 at 0900 hours and ending with Station 30 at 1615. On September 24 and October 8, paired samples from sunlit and shaded areas were also collected from an area in the vicinity of Transect 3.

Temperature and relative humidity observations were made with a sling psychrometer at the beginning and end of each sampling period for a transect at the time each sample was taken for Transect 3 on September 22, and for each pair of samples on September 24 and October 8. The intensity of the reflected light from the litter surface was measured with a photronic photographic exposure meter for most sampling periods at each station. Usually these readings were made at 5- to 10-minute intervals starting 30 to 40 minutes before the samples were collected. For Transect 3 on September 22, reflected light readings were made at all stations each time a sample was collected.

Sampling was started in July, and continued at various intervals and times of day until late October. Not all stations of a transect were sampled at one time, nor were all transects sampled throughout the season.

Transect Descriptions

Transect 1 was laid out in a southeast to north-

west direction in a dense pole-sized stand of timber approximately 60 feet in height. The crown canopy was also dense, and little direct solar radiation reached the surface — sunlit patches were small and quite uniformly distributed. The litter was about 3.5 inches deep, with a generally uniform surface. However, the litter was more compact at Station 5 because of a deer bed, and some mixing of the surface needles with lower layers occurred when the bed was used. Also, a dead limb with branches at Station 24 held the surface needles somewhat above the more compact litter below.

Transect 2 ran in a southwest to northeast direction in a moderately dense stand of timber averaging 60 feet in height. Openings in the crown canopy were larger than for Transect 1, and the transect crossed an opening about 50 feet in diameter between Stations 10 and 20. Litter within the timber stand was uniform and about 3 inches deep. The surface of the large opening was covered with a thin layer of pine needles and sedge. Some grass also grew under the larger openings in the crown canopy within the timber stand.

Transect 3 was established in a west to east direction in a medium density timber stand with trees averaging 50 feet in height. Individual tree crowns were dense, but openings in the crown canopy were larger and less uniformly distributed than for Transect 1. The litter was about 3 inches deep with a uniform surface.

Transect 4 ran in a south-southeast to north-northwest direction in a timber stand of moderate density and with trees about 70 feet in height. Most of the transect was under a narrow alley between the crowns. The adjoining canopy was generally dense, and there were few other openings. The litter surface was uniform, but the litter varied in depth from 4.5 inches at the SSE end of the transect to 2.5 inches at the NNW end.

Transect 5 started near the edge of a closed, mature timber stand, and then ran in a northerly direction across an open area between Stations 16 and 26, and thence into a young, dense stand of saplings with thin crowns. The litter was about 5 inches deep under the mature timber and 3 inches deep in the sapling stand. The open area was covered with pine needles to a depth of about 0.5 inches, with some moss and sedge also present.

Transect 6 was laid out from west to east in an

open, mature timber stand. The crown canopy was mostly closed, but there were some small openings over the transect. The litter was about 4 inches deep with a uniform surface.

Environmental Conditions

The last heavy rainfall of the season in the study area came on June 14. Additional light rain fell on July 8 and 9, but did not penetrate deeply into the litter layer, and no other penetrating rains occurred during the season. Stable weather conditions

with generally clear skies usually prevailed for several days before each sampling period. Wind speeds within the timber stands were always low.

Although the surface needles appeared dry when the sampling was started on July 7, the lower third of the litter layer and the soil beneath were still saturated from the June rain and the winter snow. Heavy dew formation was common in July and early August as a result of the cool nighttime temperatures and the high moisture content of the soil and lower litter layers. By September, however, the entire litter layer and soil were dry and dew formation was rare.

RESULTS AND DISCUSSION

Surface litter moisture samples were obtained for a wide variety of environmental conditions and timber stand characteristics. Considerable variation in fuel moisture was found among stations of a transect, and also in the moisture patterns between transects. In general, the variance was greatest when the fuel moisture was high, and tended to decrease as the season progressed. Sampling dates and times, air temperature and relative humidity, and a summary of the surface litter moistures observed for each transect are shown in *table 1*.

Most of the observed differences in moisture content between stations and transects appear to have been caused by variations in the amount and patterns of solar radiation reaching the litter surface. During July and early August, the residual effects of winter snow and the heavy rain of June 14, and the effects of nighttime back radiation were also apparent.

Radiation affects fuel moisture through the complex processes by which the earth's surface and the atmosphere are heated and cooled and the effect of the heating and cooling on relative humidity and fuel temperature. Dead wildland fuels are hygroscopic, and in the absence of free water the moisture content of a piece of fuel depends mostly on the relative humidity of the air immediately surrounding it, but fuel temperature also has an effect. Fuel at a given temperature and exposed to a constant relative humidity will eventually attain a moisture content that is in equilibrium with that humidity and temperature. The moisture content will then remain constant until the humidity or fuel temperature changes. The

time required for the moisture to reach the equilibrium value depends principally on the fuel characteristics and the difference between the actual and equilibrium moistures. Temperature and relative humidity are often continuously changing under natural conditions, and consequently the actual moisture in wildland fuels at any given time usually lags behind the equilibrium moisture. The trend in actual moisture, however, is always toward the appropriate equilibrium moisture for the existing conditions.

As long as the mixing ratio² of the air remains constant, the relative humidity varies inversely with the air temperature — decreasing as the air temperature goes up and increasing as the air temperature goes down. The main source of heat for warming the air is solar radiation. But because air is nearly transparent to the shortwave solar radiation, the heating is accomplished indirectly. The radiant energy must first strike some solid or semiopaque material before it is converted to thermal energy. Where vegetation is sparse, the conversion takes place principally at the ground surface, thus raising its temperature. The air next to the surface is heated by conduction, and the heat is transferred to deeper air layers by convection. The air is also warmed through absorption of longwave radiation from the heated ground surface by the carbon dioxide and water vapor in the air. Time is required to transfer the heat from the ground surface to the air above it, however, and consequently the air temperature lags behind the surface temperature, with the amount of lag in-

²Weight of water vapor per unit weight of dry air.

Table 1 — Summary of sampling dates and times, air temperature, relative humidity, and surface litter moisture for six transects in ponderosa pine timber in northern California.

Transect	Date sampled	Time sampled	Stations sampled	Air temperature ¹	Relative humidity ¹	Mean	Moisture range	Variance
				°F			Percent	
1	Jul. 7	1310	30	74	29 — 32	8.1	7.4 — 9.2	.18
	Jul. 24	0804	30	61 — 64	64 — 61	15.5	14.2 — 17.2	.36
2	Jul. 7	1350	30	75	31 — 36	6.5	3.7 — 8.8	2.02
	Jul. 24	0823	30	66 — 68	67 — 60	16.7	14.1 — 22.0	5.94
	Jul. 31	1320	12	86	29	6.9	8.9 — 11.7	.89
	Aug. 14	1057	9	81	29	10.4	5.3 — 8.3	.85
3	Jul. 21	1400	29	91 — 90	31	7.2	4.7 — 9.0	1.51
	Sept. 21	1030	15	81	19	7.3	5.8 — 8.3	.32
	Sept. 21	1520	15	84	14	6.0	5.4 — 6.3	.23
	Sept. 22	(²)	29	74 — 87	28 — 12	(²)	(²)	(²)
	Sept. 30	1130	15	71 — 72	20 — 21	7.1	6.2 — 7.7	.18
	Oct. 8	1000	15	75 — 76	18 — 16	8.1	7.8 — 9.1	.14
4	Jul. 21	1400	30	91 — 90	31	8.0	6.5 — 9.4	.44
	Sept. 21	1120	15	81	19	7.7	7.2 — 8.0	.04
	Sept. 23	1400	30	86	12	6.4	5.9 — 6.9	.06
	Sept. 30	0920	30	63 — 65	40 — 34	10.0	9.2 — 11.1	.14
5	Jul. 29	1330	30	85 — 84	33 — 32	7.8	5.6 — 13.3	3.24
	Jul. 31	1030	30	79 — 81	42 — 31	10.2	6.2 — 13.8	2.27
	Sept. 21	1320	15	85	15	6.9	4.9 — 8.8	1.13
	Sept. 30	1515	30	75	15	7.4	5.8 — 8.4	.50
	Oct. 8	1311	15	82	14	6.8	5.7 — 7.8	.42
6	Jul. 31	1120	29	82 — 83	29 — 31	8.6	5.6 — 10.3	1.20
	Sept. 21	1400	15	86 — 85	12 — 15	6.1	5.5 — 7.0	.32
	Sept. 24	1005	15	72 — 80	35 — 22	7.8	6.5 — 8.7	.46
	Sept. 30	1304	30	75 — 74	20 — 19	6.9	6.1 — 7.9	.25
	Oct. 8	1325	15	82	14 — 13	6.2	5.4 — 7.0	.19
	Oct. 23	1123	11	62	25	9.1	8.4 — 9.9	.23

¹Beginning and end of sampling period.

²Stations were sampled 15 minutes apart from 0900 to 1615 hours.

creasing as the distance above the surface increases. During the daytime in the open, then, a temperature gradient, with the air temperature decreasing with height above the ground, is usually present.

Although the earth is always losing heat by longwave radiation, the incoming solar radiation and heating exceeds this loss during most of the daylight hours. At night, however, the back radiation heat loss becomes dominant and the surface of the earth is cooled, in turn cooling the air next to it. The air at higher levels is cooled by mixing with the cold surface layer and also by radiation losses. Consequently, at night the air temperature gradient is opposite that of daytime, and the air temperature increases with height above the ground.

Because of the inverse relationship of relative humidity to air temperature, the relative humidity

gradients are the reverse of the air temperature gradients. However, the change in relative humidity with height may not be in direct proportion to the change in temperature because a mixing ratio gradient may also be present. Moist soil and surface fuels may cause the mixing ratio to increase toward the surface, and extremely dry soil and fuel may cause it to decrease. In general, however, the fuel on the surface is usually exposed to higher temperatures and lower humidity during the day than are fuels above the surface or in the shade, and to lower temperature and higher humidity at night.

In timbered areas the tree crowns replace the ground surface as the principal absorber of solar radiation. The crowns do not get as hot as the ground surface in the open, however, because of the different radiation-absorbing characteristics of the living material, the cooling effects of trans-

piration, and the greater depth through which the radiation is distributed. Air within the stand must also be warmed by downward mixing of the heated air in the crowns, and since warm air tends to rise, the mixing is usually slow. At night the tree crowns reduce radiation heat losses from the litter surface and air within the stand. Consequently, air temperature and relative humidity in the stand have less diurnal fluctuation than in the open. The vertical temperature gradients are also less, and in dense stands the temperature and humidity at the litter surface is often about the same as that measured at the conventional instrument shelter height.

In all but the densest of stands, however, some solar radiation reaches the litter surface through openings in the crown canopy, forming patterns of sunlight on the surface. Litter in the sunlit patches is heated more than shaded areas; therefore the relative humidity of the air surrounding the fuel is lower. At night, the litter below the openings is cooled most by radiation losses, and this results in lower fuel temperature and higher relative humidity than for adjacent areas. If the surface is cooled sufficiently dew or frost may form, particularly when the soil and lower litter layers are moist.

Except for a narrow band near the equator, the sun is never directly overhead, and consequently the solar radiation must usually come through the crown openings at an angle. Because of the radiation angle, timber stand characteristics such as tree height, crown depth and density, opening size and shape, and tree spacing greatly affect the patterns of sunlight reaching the surface and the intensity of the radiation. The sunlit patches on the litter surface move about and the radiation intensity also varies as the sun angle changes during the day. In the northern hemisphere, the solar radiation tends to be directed west of the vertical projection of the opening in the morning, north at noon, and east in the afternoon. As a result, the area cooled most at night may not receive solar radiation at all during the day when the crown opening is small, and only the northern part of the area under the larger openings is likely to be exposed to much solar radiation. The patterns of solar radiation on the surface and radiation intensity also vary with the time of year as the position of the sun with respect to the equator changes.

Surface litter under timber stands, then, is subject to complex and variable patterns of heating and cooling by radiation. Because of the interrela-

tionships of radiation, temperature, relative humidity, and fuel moisture, the patterns of litter moisture can be equally complex and variable. Many of the effects of heating and cooling by radiation appeared in this study, and the data collected gives an insight into the magnitude of the moisture variations that may occur.

Solar Radiation Effects

As indicated earlier, the stations of Transect 3 were sampled at 15-minute intervals throughout the day on September 22, and reflected light readings were taken at all stations each time a moisture sample was collected. These data provided much information on the variation in the amount of solar radiation received by the litter, and the effect of this variation on the litter moisture pattern. The reflected light intensities were normalized to indexes on a scale of 0 to 100. When tabulated by station and time, the indexes show the variation in the intensity of solar radiation reaching the surface at different stations and the manner in which the sunlit areas changed with time (*table 2*). All of the stations received some sunlight during the day, but the relative intensity of the radiation and the time it persisted varied widely among stations. All of the stations were in nearly full shade for half or more of the 7.5-hour period, as could be expected from the dense crown canopy over the transect. Little direct sunlight reached the litter surface after 1500 hours, and only 10 stations had reflected light intensities greater than 50 percent of the maximum observed value at any time. The tendency for the sunlit areas to move from west to east because of the changing sun angle during the day is also manifest in *table 2*, where all of the indexes greater than that for full shade have been delineated.

For convenience in presentation, the air temperature, relative humidity, and litter moisture for Transect 3 on September 22 were converted to indexes based on the highest observed value for the individual parameters (*fig. 1*). The air temperature rose slowly during the forenoon, and then remained constant until late afternoon. The relative humidity pattern was generally the inverse of the air temperature pattern, decreasing during the forenoon, and then changing little until late afternoon. The small dip in the humidity between 1445 and 1530 hours was apparently caused by an influx of drier air from outside the timber stand — the mixing ratio also decreased at this time.

Taken as a whole, the moisture content along the transect decreased most of the day, and then increased somewhat in the late afternoon in much the same way as the relative humidity pattern. However, litter samples taken from adjacent stations and only 15 minutes apart often deviated considerably from the general trend, particularly in the afternoon. To determine if these deviations were associated with the variation in solar radiation reaching the litter at the different stations, the total of the light intensity readings at each station

prior to the time the sample was collected was compared to the moisture content at the station. Both moisture content and light intensity totals were converted to indexes on a scale of 0 to 100, with the moisture index based on the minimum observed value and the light index on the highest total for a station. Thus, the moisture index decreases with decreasing moisture content, but the light index decreases with increasing total light intensity to the time of the sample. Consequently, the indexes will move in the same direction if litter

Table 2--Reflected light indexes for Transect 3 on September 22 (values greater than that for full shade outlined to show movement of sunlit areas from west to east)

Time	Station																														East
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
0900	18	3	2	2	2	2	2	2	4	5	17	43	6	4	2	4	2	2	4	7	3	2	2	11	11	5	2	2	4	50	
0915	9	11	4	2	2	2	2	3	2	5	5	36	21	7	3	2	4	2	5	29	5	18	2	4	6	29	9	3	4	3	
0930	5	9	6	1	5	2	2	2	2	2	11	11	23	29	6	2	2	4	2	11	10	18	6	3	4	6	29	6	3	10	
0945	6	4	5	10	11	5	5	2	2	2	4	29	18	57	29	3	2	2	4	9	23	14	50	4	4	3	11	13	6	4	
1000	5	11	5	21	15	7	4	2	2	2	4	6	25	57	32	11	7	2	3	6	16	11	21	57	4	3	3	11	7	6	
1015	14	4	4	11	39	11	5	11	2	2	2	7	9	36	71	18	18	6	2	2	11	16	11	64	50	5	3	4	9	5	
1030	4	29	4	4	14	32	7	18	11	2	2	5	5	14	71	20	25	43	4	2	2	46	14	32	64	21	4	4	3	6	
1045	5	5	11	5	5	25	6	9	29	4	2	2	6	3	36	29	26	57	14	3	4	5	29	8	64	36	23	3	3	2	
1100	26	4	21	18	18	4	18	4	11	18	5	2	2	4	16	18	16	64	50	18	2	4	9	21	29	64	30	11	4	3	
1115	11	16	3	11	21	29	13	7	8	13	23	11	2	2	2	21	14	57	93	25	16	3	4	9	11	36	64	16	19	3	
1130	21	14	14	6	21	32	10	6	4	4	32	11	11	3	3	3	4	29	100	36	21	14	3	4	7	18	36	57	6	29	
1145	18	14	18	7	21	29	25	4	21	4	6	11	25	7	3	3	3	14	93	93	21	9	18	3	4	5	23	50	14	18	
1200	4	25	7	16	7	10	29	9	9	9	6	7	13	18	5	6	3	3	11	96	46	9	36	5	4	4	6	32	14	6	
1215	9	4	7	7	14	11	11	25	4	7	13	4	7	10	14	9	6	4	4	5	50	21	14	14	11	5	4	5	7	13	
1230	57	25	3	7	5	18	11	21	5	4	21	11	4	9	9	21	7	4	4	5	4	29	9	23	16	14	11	3	3	6	
1245	9	43	50	3	3	10	14	7	6	10	6	23	7	6	4	11	29	5	3	6	20	10	5	10	14	10	36	36	4	3	
1300	4	6	21	43	4	3	14	21	6	10	8	8	9	7	7	5	13	29	4	4	9	13	29	25	11	29	9	36	32	4	
1315	21	6	11	11	4	7	4	6	27	5	7	11	4	9	43	9	5	14	11	4	4	18	18	36	36	18	29	16	14	11	
1330	4	10	18	4	7	4	3	2	5	18	5	27	8	4	8	43	21	7	4	6	11	5	4	50	25	36	14	14	19	5	
1345	5	4	6	18	18	3	5	7	2	2	9	13	10	9	4	11	36	29	16	2	4	5	9	6	36	29	16	8	13	7	
1400	5	4	4	5	5	5	9	6	4	2	2	4	32	11	7	4	3	21	25	18	4	3	4	6	13	18	14	18	11	16	
1415	26	43	18	6	3	3	4	2	9	6	5	2	4	11	14	5	4	3	11	21	16	5	4	5	7	16	7	5	25	13	
1430	4	16	46	29	14	10	10	10	6	11	4	5	3	10	9	10	4	3	2	6	4	6	13	11	7	6	9	7	11	4	
1445	2	4	5	21	36	14	7	4	8	7	14	5	4	2	6	14	14	5	4	2	6	4	6	10	9	16	6	10	5	5	
1500	1	2	3	3	4	14	11	4	3	3	2	3	5	3	6	4	5	4	2	3	2	3	4	4	4	3	7	7	6	6	
1515	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	6	3	9	3	2	2	2	2	2	3	2	2	2	4	3	
1530	11	6	9	7	3	3	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
1545	2	2	2	2	2	5	6	4	4	3	4	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	2
1600	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	
1615	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	1	1	1	1	1	1	1	1	2	2	2	1	1	1	

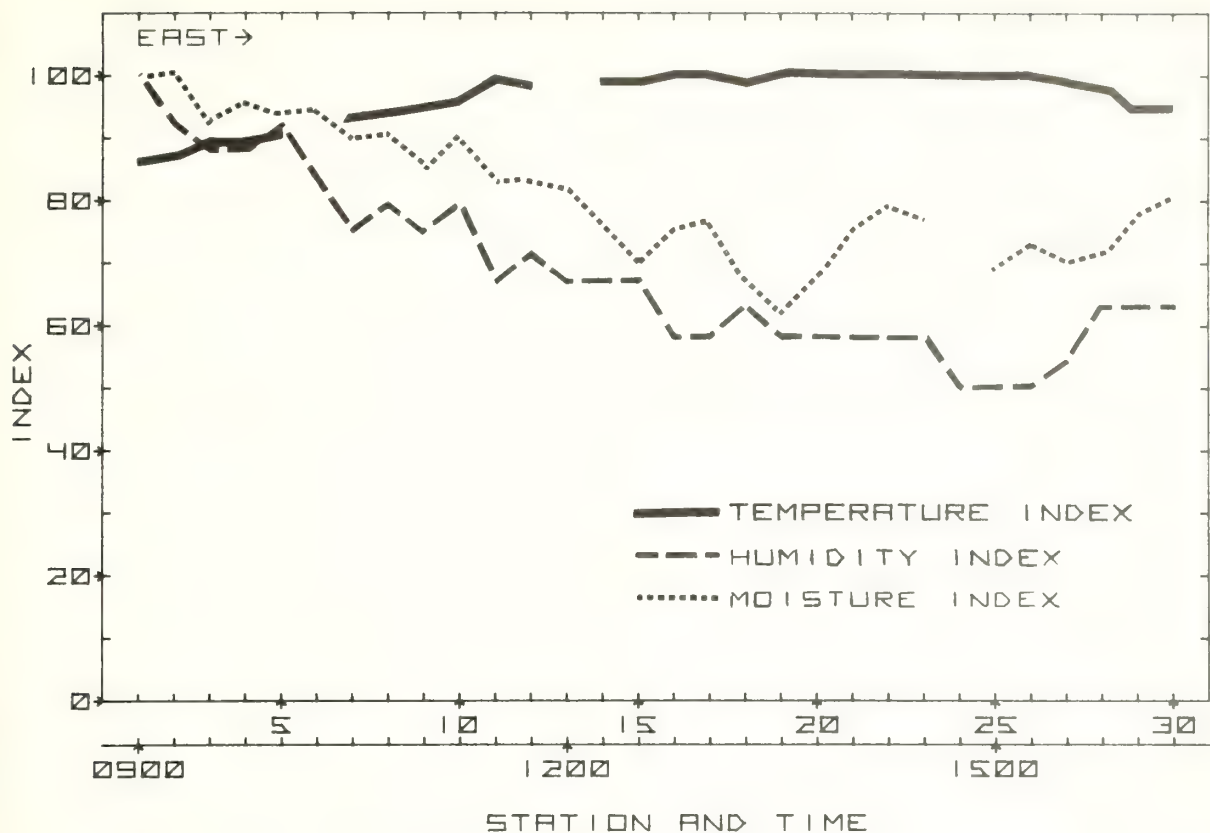


Figure 1 — Temperature, humidity, and moisture indexes for Transect 3 on September 22

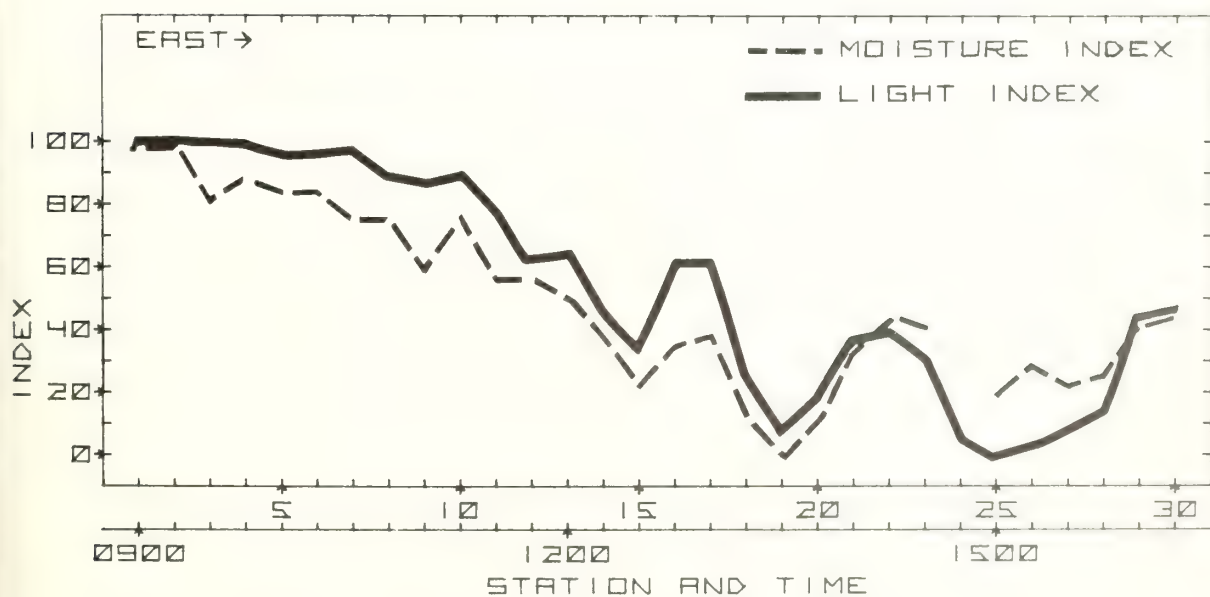


Figure 2 — Moisture and reflected light indexes for Transect 3 on September 22

moisture is associated with the amount of solar radiation received at a station. When the two indexes are plotted together, a marked similarity in the patterns of moisture and total reflected light intensity is apparent (*fig. 2*).

The nature of the relationship between fuel moisture and the amount of solar radiation (as indicated by the reflected light readings) is shown by statistical analysis. A logarithmic curve was fitted to the data, giving the equation

$$M = 10.496 - 0.71221 \ln I_a \quad (1)$$

where

M = moisture content in percent

I_a = total light intensity to time of sample

$\ln$ = natural logarithm

The correlation coefficient for this relationship is 0.945. Therefore about 89 percent of the variation in moisture along the transect was accounted for by the variation in the total amount of solar radiation received by the litter to the time each sample was collected.

The observations of air temperature and humidity with the sling psychrometer were made 3 to 4 feet above the ground. Because of the air mixing process, these observations are indicative of the general temperature and humidity of the air within the timber stand, and do not necessarily represent the surface conditions — particularly for sunlit areas. In shaded areas, however, the temperature and humidity gradients are small, so the observations do provide an approximation of the surface conditions for such areas. All of the stations of the transect were in shade at least part of the day, consequently the substantial change in relative humidity during the long sampling period might be expected to cause variation in the moisture content of the litter. That is, if all of the stations had been in full shade throughout the day, the moisture content would still have varied along the transect because of the change in relative humidity of the air from the beginning to the end of the sampling period. Adding relative humidity to the analysis through multiple regression techniques, however, did not significantly improve the correlation or the accuracy of equation (1). This is the result of the close interrelationships between solar radiation, air temperature, and relative humidity. Except for a short period near the end of the sampling period, the mixing ratio of the air remained virtually constant, and consequently the change in the relative humidity during the day

was controlled almost entirely by the change in air temperature. In turn, air temperature is highly dependent on the total amount of solar radiation received up to a given time. Therefore the amount of solar radiation indirectly controlled the relative humidity.

Because actual fuel moisture lags behind the equilibrium value when relative humidity and temperature are changing, the duration of solar radiation on a given area of litter is an important factor in spatial moisture variations. The data collected on September 22 for Transect 3 are not well suited for determining the precise effect of solar radiation duration and intensity on moisture content — the independent effects of the various influences on the moisture content at each station cannot readily be separated from the combined effects with the available data. However, some insight as to the importance of solar radiation duration can be obtained by correlating reflected light intensities for various time periods with the moisture content of the litter.

Relating the logarithm of the maximum light intensity previous to the time of the moisture sample at each station with the moisture content produced a correlation coefficient of 0.907. This is somewhat lower than the coefficient of 0.945 obtained with the total light intensity to the time of the sample, but the relationship is adequate to explain about 82 percent of the moisture variation among the stations. The logarithm of the total of the maximum light intensity and the highest reading immediately preceding or following it gave a correlation coefficient of 0.940 — almost the same as for the total light intensity to the time of the sample. The logarithm of the total of three consecutive light intensity readings, including the maximum, resulted in a correlation coefficient of 0.954 for the intensity-moisture relationship. Including the logarithm of the relative humidity in the analysis increased the correlation coefficient to 0.967. Approximately 94 percent of the moisture variation along the transect is explained by this latter combination. The equation for the relationship is:

$$M = 6.38 - 0.7179 I_b + 1.3122 \ln H \quad (2)$$

where

M = moisture content in percent

I_b = total of 3 consecutive light intensity readings including the maximum

H = relative humidity in percent

$\ln$ = natural logarithm

Increasing the number of light intensity observations beyond three in the analysis resulted in a decreasing correlation coefficient for both the light intensity alone or in combination with relative humidity.

Since the reflected light observations were made 15 minutes apart, the strong association between the maximum light value and moisture content indicates that the litter moisture responds very quickly to increases in solar radiation. Most of the change in moisture probably takes place in 15 minutes or less. The relatively small change in the correlation coefficient when three consecutive light readings instead of two were used suggests that equilibrium moisture is approached within 45 to 60 minutes after a change in solar radiation intensity occurs, when litter moisture is controlled primarily by litter temperature and the relative humidity of the air surrounding the needles.

Additional support for the hypothesis that the litter moisture responds quickly to exposure to solar radiation was found in the paired sun and shade samples of litter collected in the general area of Transect 3 on September 24 and October 8. On September 24 the paired samples were collected at half-hour intervals from 1000 to 1600 hours. The sun samples were collected from areas that had been exposed to full sunlight for at least 30 minutes. The shade samples were taken from

areas known to have been in full shade for at least 30 minutes, but likely were shaded longer since these areas were usually on the north side of trees. The mean moisture content of the sun samples was 4.0 percent, and that of the shade samples 6.2 percent (table 3). The difference in the mean moisture contents is statistically significant at the 1 percent level.

Two pairs of samples were collected at 1340 hours on October 8 from areas that had been in the sun or shade for at least 3 hours. The mean moisture for the two samples collected in the sunlit areas was 3.2 percent, while the mean of the samples in the shade was 6.2 percent — the same as for the shade samples on September 24. The air temperature was 83₁ F and the relative humidity 13 percent, not greatly different than on September 24. Despite the much longer exposure to direct solar radiation, the moisture content of the sun samples collected on October 8 was not much lower than on September 24, again suggesting that most of the change in litter moisture occurs shortly after exposure to solar radiation.

That moisture content of pine needles reacts quickly to changes in the environmental conditions is also confirmed by a laboratory study of the moisture response of *Pinus radiata* needles (King and Linton 1963). In this study pine needles at equilibrium moisture with a temperature of 84₁ F and a relative humidity of 59 percent

Table 3 — Moisture content of sun and shade samples for Transect 3 on September 24

Time	Air temperature	Air relative humidity	Moisture content	
			Sun	Shade
	°F		Percent	
1100	83	17	4.8	6.8
1130	85	15	4.1	7.4
1200	85	13	4.1	6.8
1230	87	12	3.9	5.9
1300	87	14	3.6	5.3
1330	84	14	4.7	7.1
1400	85	15	4.8	6.9
1430	85	15	2.9	5.3
1500	84	16	4.3	6.6
1530	84	16	2.5	4.1
1600	85	13	3.2	5.6
Mean			4.0	6.2
Standard deviation			.94	1.00
Standard error			.28	.30
Coefficient of variation			23.4	16.3

reached 50, 75, and 90 percent of the new equilibrium value in 7.4, 12, and 21 minutes, respectively, when the temperature was changed to 134₁ F and the relative humidity to 19 percent. The moisture response of surface needles in the natural situation is likely to be somewhat slower, however, because the lower litter layers provide a moisture source not available to isolated needles in a laboratory study.

Although litter moisture responds rapidly to exposure to solar radiation, attempts to correlate the reflected light readings taken during the 30- to 40-minute period prior to the time of sampling with litter moisture for the different transects gave inconsistent results. High light intensity was usually associated with relatively low moisture, but low moisture was also frequently found when the light intensity indicated full shade. The explanation for this seeming anomaly is found in the way that litter moisture responds to diurnal changes in temperature and relative humidity and the effects of duration and intensity of solar radiation on intermittently exposed litter.

Under fair weather conditions, surface and air temperatures increase during the day and decrease at night, and the relative humidity follows the inverse of this pattern. Because of the close interrelationships of temperature, relative humidity, and fuel moisture, the diurnal equilibrium moisture pattern is similar to that of the relative humidity. But temperature and humidity are usually changing more rapidly than the litter can lose or absorb moisture during much of the diurnal cycle, and consequently the actual litter moisture is usually higher than the equilibrium moisture during the day, and lower at night. Only during the period in the early evening and morning when the trends in temperature and humidity are reversing can the litter moisture "catch up" with the equilibrium moisture.

The temperature of previously shaded litter increases when it is exposed to solar radiation, thus reducing the relative humidity of the air surrounding the needles. The moisture content of the litter then moves toward the lower equilibrium for the new conditions. But when the litter is again shaded, it may or may not increase in moisture content. Because of the lag in moisture behind changing temperature and humidity, the litter cannot attain equilibrium when the exposure to radiation is brief — it just moves closer to the equilibrium value for the shaded condition. If the exposure to radiation is long enough for the litter

moisture to reach equilibrium for the exposed conditions, its moisture will likely increase somewhat when it is again shaded. In either case, however, the moisture content of litter that has been exposed to solar radiation will be less than litter that has not been exposed, and a lower moisture will persist at least until the evening reversal period in the trends of temperature and relative humidity.

The likelihood that the moisture of litter exposed to solar radiation and then shaded will remain below that of continuously shaded litter for a considerable time is enhanced by the tendency of wildland fuels to have a lower equilibrium moisture for a given temperature and humidity when they are absorbing moisture than when they are losing it (Blackmarr 1971).

The temperature to which the litter and the air next to it can be raised and the amount that the relative humidity can thereby be reduced, depends on the intensity of the solar radiation as well as the length of exposure. Consequently, litter exposed to intense radiation for a short time may reach a lower moisture than that of litter exposed to lower radiation intensity for a longer period. For example, Stations 19 and 22 of Transect 3 on September 22 were in full shade at the time the litter samples were collected at 1330 and 1430 hours respectively (*table 2*). But the pattern of exposure to solar radiation of the two stations was quite different. Prior to the sampling time, Station 19 was in full shade or exposed only to low intensity radiation except for a period of very strong radiation between 1100 and 1200 hours. Station 22, on the other hand, was exposed to more sunlight than Station 19, but all of the radiation was of low to moderate intensity. As a result of the relatively short exposure to high intensity radiation, the moisture at Station 19 reached a lower level than that at Station 22, and this lower moisture persisted to the time of the sample (*fig. 1*).

Because of the strong relationship between solar radiation and litter moisture, and the persistence of lower moisture in litter that has been exposed to radiation, the history of the previous exposure of an area to solar radiation is more important in determining the litter moisture at any given time than are the conditions at that time. Consequently, spatial variations in the moisture content of the litter may exist even though all of the litter is in shade at the time the moisture determination is made. The moisture variations

created by solar radiation can also be carried over from one day to the next unless the temperature and relative humidity remain constant, or only change very slowly, for a long enough time at the evening or morning reversal periods for all of the litter to approach equilibrium.

Radiation Cooling Effects

Early in the morning, dark-colored patches of litter of varying size and irregular shape sometimes appear in the litter under a timber stand. Examination of these patches will show that the litter in these areas is very moist, and it is this moisture that gives the litter its darker color. The patches of moist litter appear directly under openings in the crown canopy, and are caused by dew formation when nighttime radiation losses through the openings are sufficient to cool the surface air below its dewpoint. They are most likely to appear when the general nighttime air temperatures are cool and the soil and lower litter layers are moist. Even though dew does not form, however, the areas under the openings will be cooled more and therefore have higher humidity and fuel moisture than the surrounding areas under the timber stand.

Diagrams of the openings in the crown canopy above each of the transects were made when the study was started. Unfortunately, these data have been lost, and since the exact location of many of the crown openings is not known, the precise effect of radiation cooling cannot be determined for all of the transects. The location of the large openings along Transects 2 and 5 are known, however, and the data collected in July for these transects clearly show the effects of dew formation on the moisture patterns. The openings were large enough to permit extensive radiation cooling at night, and heavy dew frequently occurred in these openings as well as outside the timber stands during July and early August.

Moisture samples taken in the early forenoon of July 24 on Transect 2 showed considerably higher moisture in the central part of the large opening than in the timber stand where nocturnal cooling was reduced by the tree crowns (*fig. 3*). At the time of the afternoon sampling period on July 7 for this transect, the highest moisture was in the timber stand. However, the moisture was also relatively high over much of the opening, and the highest moisture in the opening was shifted

southward as compared to the morning of July 24. Lowest moisture was found near the edges of the opening, particularly on the northern side (*fig. 4*).

The change in the pattern of moisture variation between the morning and afternoon sampling periods was caused by the angle at which the solar radiation reached the transect. The sun is well south of being directly overhead in July at the latitude of the study site, even at noon. As a result, the south part of the opening was partially shaded by the trees on the south side of the opening — at the sampling time on July 7 about half of the opening was in full shade. This part of the transect did not receive enough solar radiation during the day to evaporate the moisture added to the litter by the dew at night. The northern part of the opening was in full sunlight most of the day, and consequently the litter moisture was lowest in this area.

Because of the heavy dew formation and the stable weather conditions, it is probable that the moisture pattern for Transect 2 on the morning of July 7 was quite similar to that on July 24. To provide a measure of the amount of drying at different points on the transect, the ratio of the moisture at each station on July 24 to that on July 7 was calculated, providing an index of relative drying along the transect. This index showed that the maximum drying occurred near the northerly side of the opening, and that the intensive drying extended into the timber stand somewhat on that side (*fig. 5*). There was also an area of intensive drying in the timber stand near the southern edge of the opening. The crown canopy was thinner in this area because of the greater tree spacing, and apparently considerable sunlight reached the surface at this point on the transect. The drying index must be considered as approximate only, since the actual moisture for the morning of July 7 is not known with certainty. However, the index pattern coincides with the pattern of solar radiation intensity that could logically be expected for the transect.

The opening on Transect 5 was about the same size as on Transect 2, and the moisture pattern along the transect was affected by dew formation during the July sampling periods in much the same way. The transect was sampled in the midforenoon of July 31, about 2 hours later in the day than for the morning sampling of Transect 2 on July 24. The peak moisture in the opening was already displaced toward the southern edge of the opening, and the drying at the northern edge was appa-

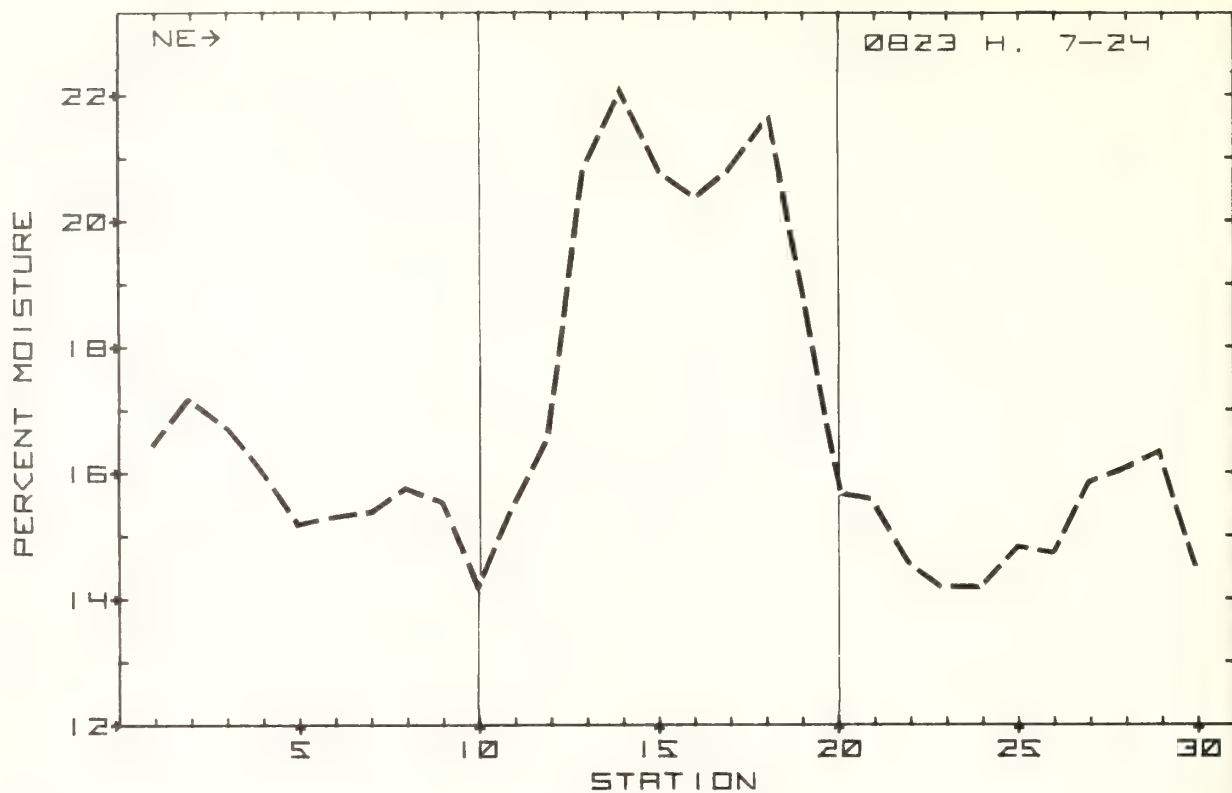


Figure 3 — Moisture content pattern for Transect 2 on July 24.

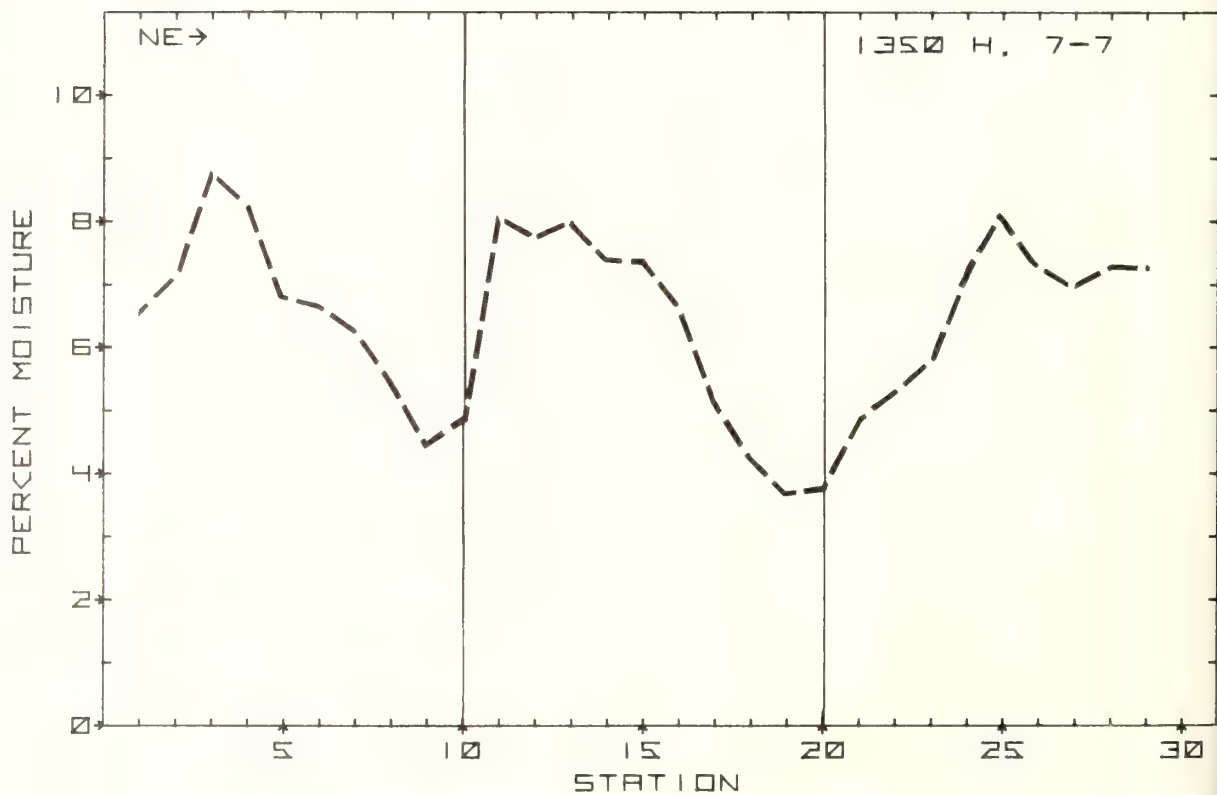


Figure 4 — Moisture content pattern for Transect 2 on July 7.

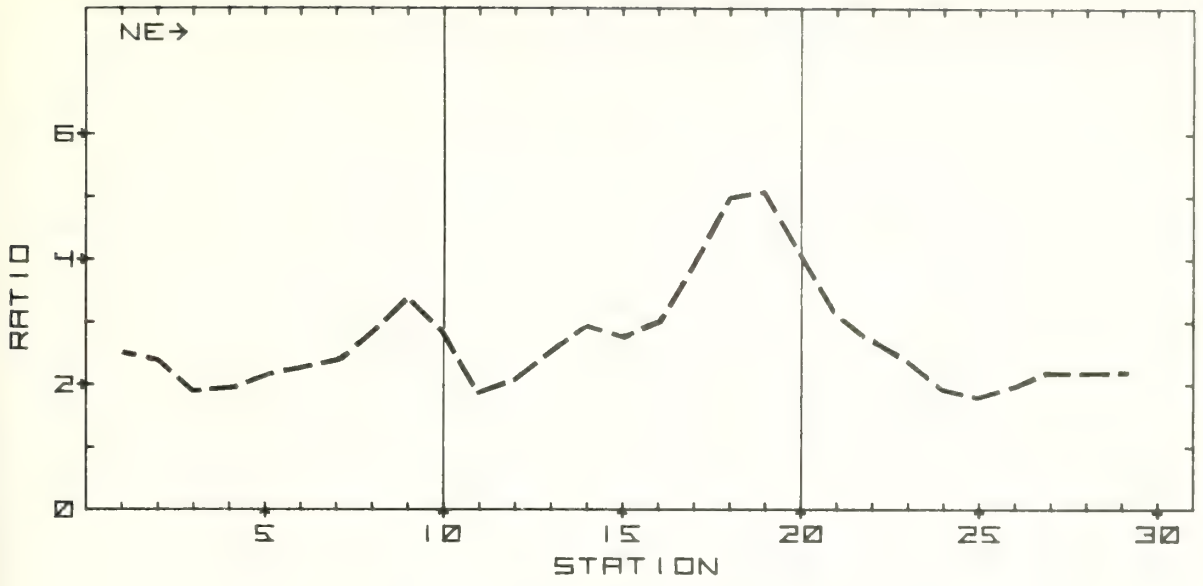


Figure 5 — Drying index for Transect 3.

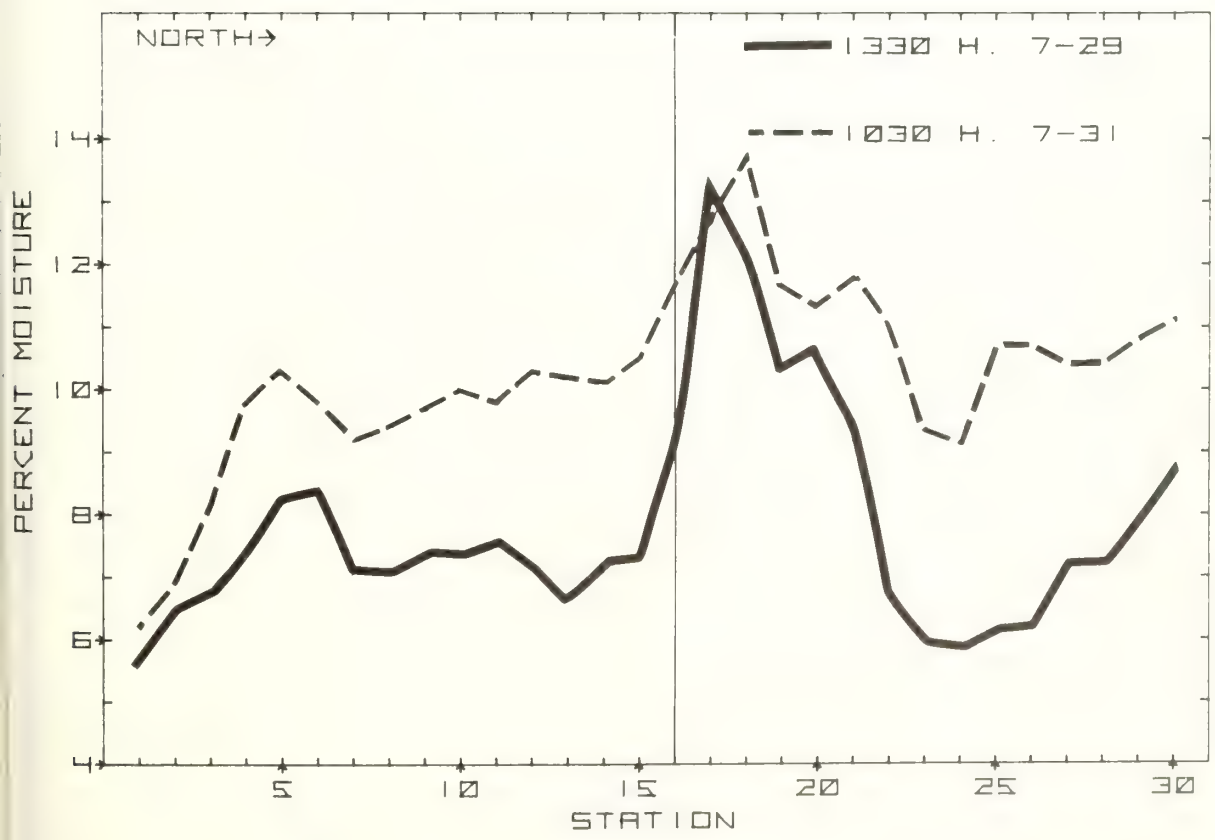


Figure 6 — Moisture content patterns for Transect 5 on July 29 and 31.

rent (*fig. 6*). The maximum moisture was still closer to the southern edge of the opening for the afternoon sampling period of July 29, and the area of low moisture on the northern side was broader, reflecting the longer exposure of the opening to solar radiation. Unlike Transect 2, however, the moisture in the timber stand remained substantially lower than that in the opening in the afternoon. The tall trees and very dense canopy of the mature timber apparently shielded the surface under the stand from direct solar radiation, and prevented much radiation cooling of the litter at night.

Transect Moisture Variations

Earlier, it was indicated that heating by solar radiation is affected by the angle of the sun as it varies during the day and with the time of year, and that the effects of solar heating and radiation cooling on litter moisture vary with the characteristics of the timber stand. The effects of heating and cooling on surface litter moisture are also modified by the moisture content of the soil and lower litter layers. This exploratory study was not comprehensive enough to establish definitive relationships between surface litter moisture and factors that affect it, and it was not designed for that purpose. However, the moisture variation patterns of the transects demonstrate the effects of solar radiation heating and radiation cooling, and give some insight as to the nature and magnitude of the moisture variations and their changes with time of day, season, and timber stand characteristics.

Transect 1 had the most dense crown canopy of all the transects, and the meager amount of direct solar radiation reaching the litter surface is reflected in the small variations in moisture along the transect found on July 7 and 24 (*fig. 7*). Highest moisture occurred in the more compact litter of the deer bed on both days. Lowest moisture in the afternoon of July 24 was at Station 24 where the fallen limb provided better aeration of the surface needles. The moisture content at this station was also relatively low on the morning of July 7, possibly indicating some "carryover" of low moisture from the preceding day. Although the general patterns of moisture variation were similar for the two sampling periods, the variance (*table 1*) was somewhat greater for the morning period when cooler temperature and greater relative humidity produced a higher average fuel moisture.

The tendency for the moisture variation between stations to decrease during the day as drying progressed was evident on other transects also. For example, the moisture variation along Transect 4 at 1120 hours on September 21 was very small — the range was less than 1 percent (*fig. 8*). But considerably more variation was found when the transect was sampled 2 hours earlier in the day on September 30.

The moisture data also indicated a strong tendency for the magnitude of the moisture variations along the transects to decrease as the season progressed. Transect 3 for example, had large moisture variations for the afternoon sampling period of July 21, but 2 months later the variations were small (*fig. 9*). Part of this difference was caused by the more nearly perpendicular, and therefore more intense solar radiation early in the season, but the high moisture content of the soil and lower litter layers was probably an important factor also. The moisture content of the soil and lower litter in areas exposed to direct solar radiation can be expected to decrease more rapidly than in shaded areas. This would deprive the surface needles of a moisture source in the exposed areas and accentuate the moisture differences between sunlit and shaded areas. Late in the season the soil and lower litter was more uniformly dry, and this along with the less intense radiation because of the lower sun angle resulted in less moisture variation.

Transect 4 also showed the seasonal trend of decreasing moisture content. Early in the season the sun was high enough to permit solar radiation to reach some parts of the transect through the narrow opening above much of the transect. This radiation, along with the high moisture content of the soil and lower litter, caused considerable variation in moisture content between stations (*fig. 10*). But later in the season the sun angle was too low to allow radiation to reach the surface through the opening, and samples taken at the same time of day indicated relatively little variation in moisture content along the transect.

Transect 6 in the mature timber stand showed the large moisture variations characteristic of strong solar radiation and high moisture content in the soil and lower litter when the transect was sampled in the forenoon of July 31 (*fig. 11*). The range of moisture content was still moderately large when the transect was sampled again during the morning of September 24, but the pattern of

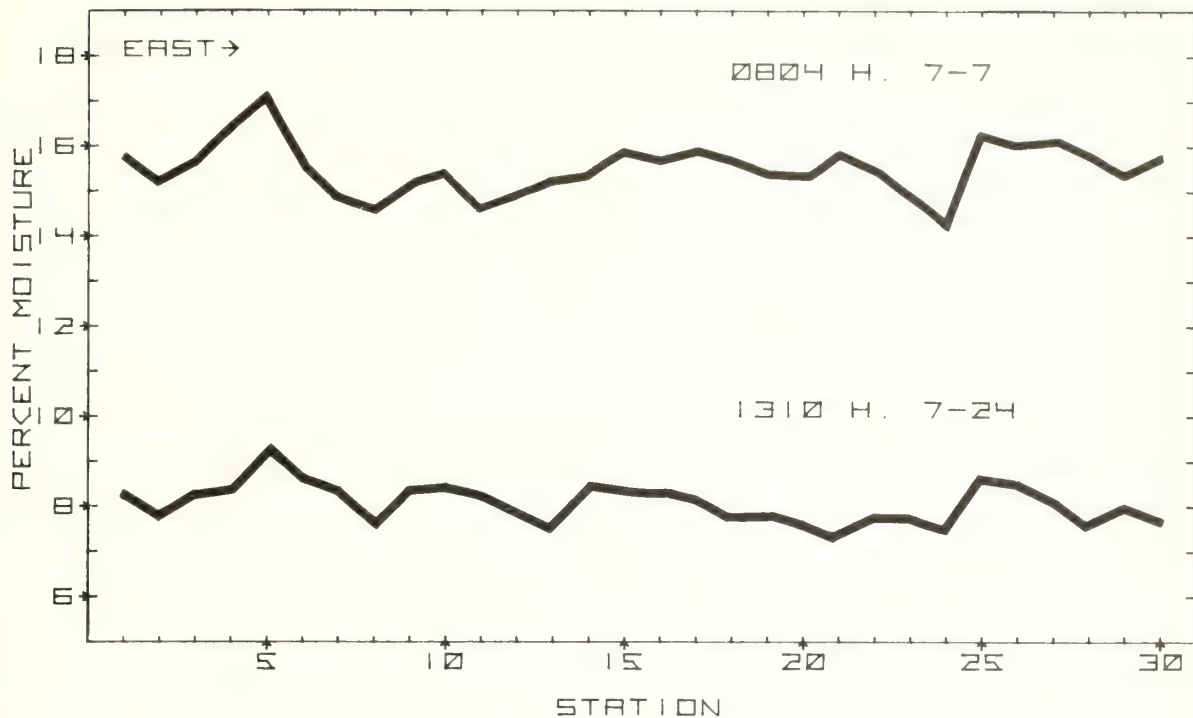


Figure 7 — Moisture content patterns for Transect 1 on July 7 and 24.

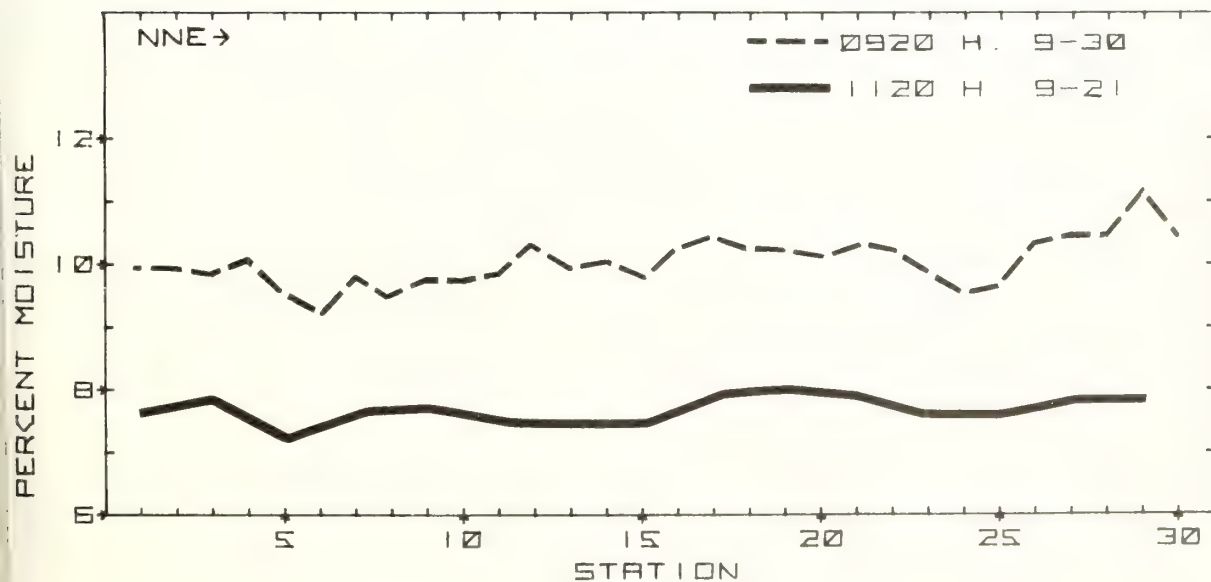


Figure 8 — Moisture content patterns for Transect 4 on September 21 and 30.

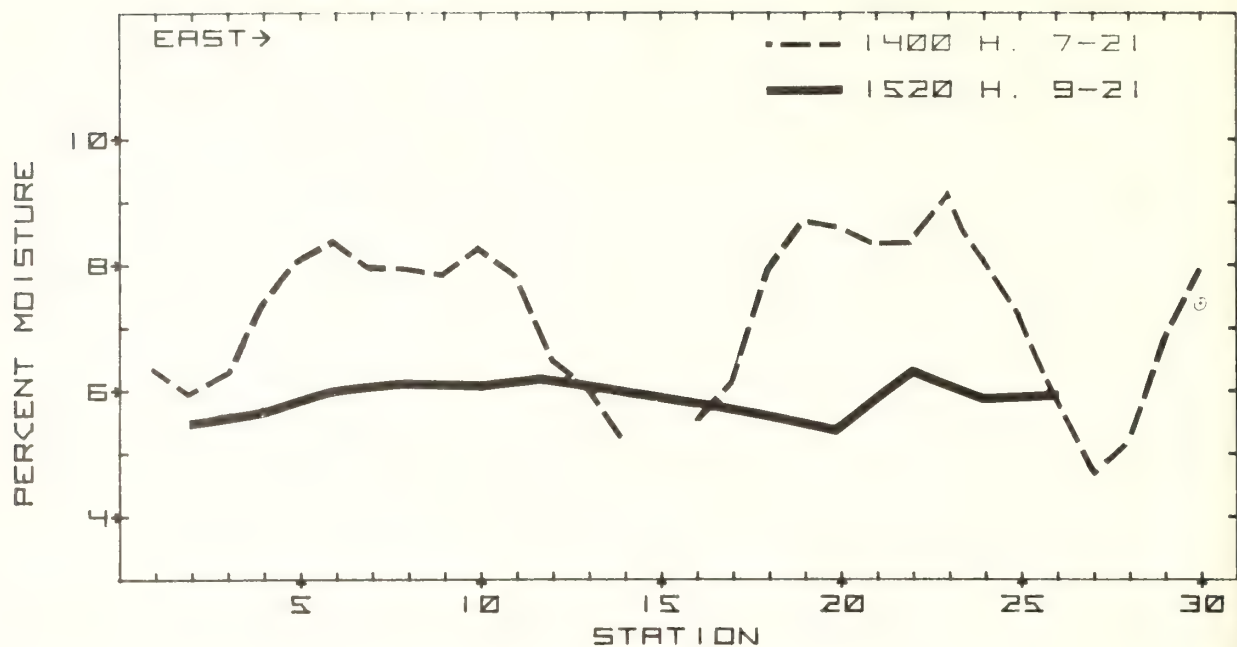


Figure 9 — Moisture content patterns for Transect 3 on July 21 and September 21.

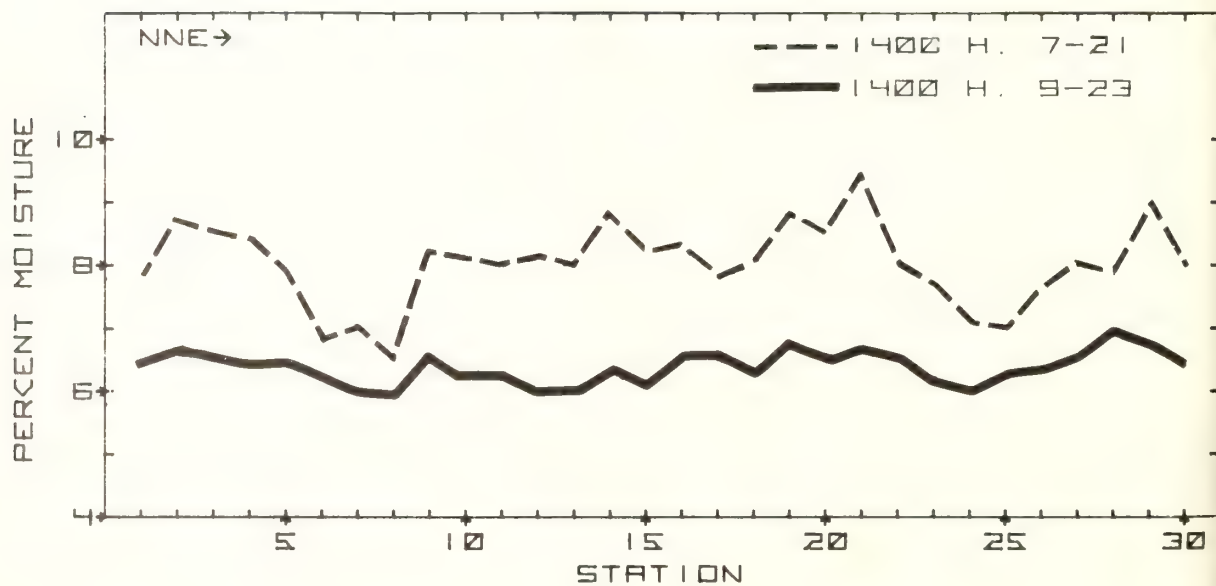


Figure 10 — Moisture content patterns for Transect 4 on July 21 and September 23.

variation showed a marked change. In September the moisture content was highest at the west end of the transect and decreased at nearly a uniform rate to the lowest value at the east end (*fig. 12*), instead of varying widely along the transect as in July. Although the range of variation was somewhat less, the same general pattern of decreasing moisture from west to east was also evident for the afternoon sampling periods in September and early October (*fig. 13*). Detailed information on the characteristics of the timber stand is insufficient to ascertain the exact cause of the change in the moisture variation pattern. Because the trees were tall and the stand was open under the crowns, however, the change in pattern is likely the result of sunlight reaching the litter surface under the crowns during the forenoon in the fall, instead of through the crowns as earlier in the season.

The moisture data collected for Transect 3 at 1030 hours on September 21 and at 1130 hours on September 30 illustrates the effect on litter moisture of the tendency for the more intense solar radiation through the crown openings to shift from west to east as the day progresses. For this comparison, the moisture values were converted to indexes based on the highest and lowest moistures for each sampling period to provide an index of relative moisture variation. Although the patterns of variation were generally similar for the two sampling periods, the pattern for the later time on September 30 was offset to the east (*fig. 14*). This shift corresponds to the shift in the higher reflected light intensities found for this transect on September 22 (*table 2*).

Because of the sun angle at the latitude of the

study site, solar radiation can penetrate into timber stands along their southerly edges and at the north edge of the larger openings in the stands. The drying index for Transect 2 (*fig. 5*) shows this "edge-effect" in a large opening. Transect 5 started near the southern edge of the timber stand, and the effect of the penetration of radiation on moisture content is apparent at the starting end of the transect as well as at the northern edge of the large opening. Reflected light intensity observations made at 10-minute intervals for 40 minutes prior to sampling on July 29 indicated that the most intense radiation was being received at the southern end of the transect, and that the intensity was nearly as great for Stations 21 to 25.

Transect 5 was sampled again on September 21, September 30, and October 8 at about the same time in the afternoon as on July 29. Lowest moisture for all three sampling periods occurred at the beginning of the transect, and the moisture increased gradually along the transect toward the northern end (*fig. 15*). The prevailing wind at the study site is usually from the southeast to southwest during the daytime, and the late season moisture pattern is probably the result of an influx of warmer and drier air from the sparsely vegetated area outside of the stand as well as penetration of radiation into the edge of the stand. The greatest range of moisture for these sampling periods was on September 21, and the least on October 8. This difference is consistent with the decreasing sun angle with time of year. Dew did not form during these days, and because of the low sun angle the large opening was shaded throughout the day. As a result, there was no apparent effect of the opening on the moisture variation pattern.

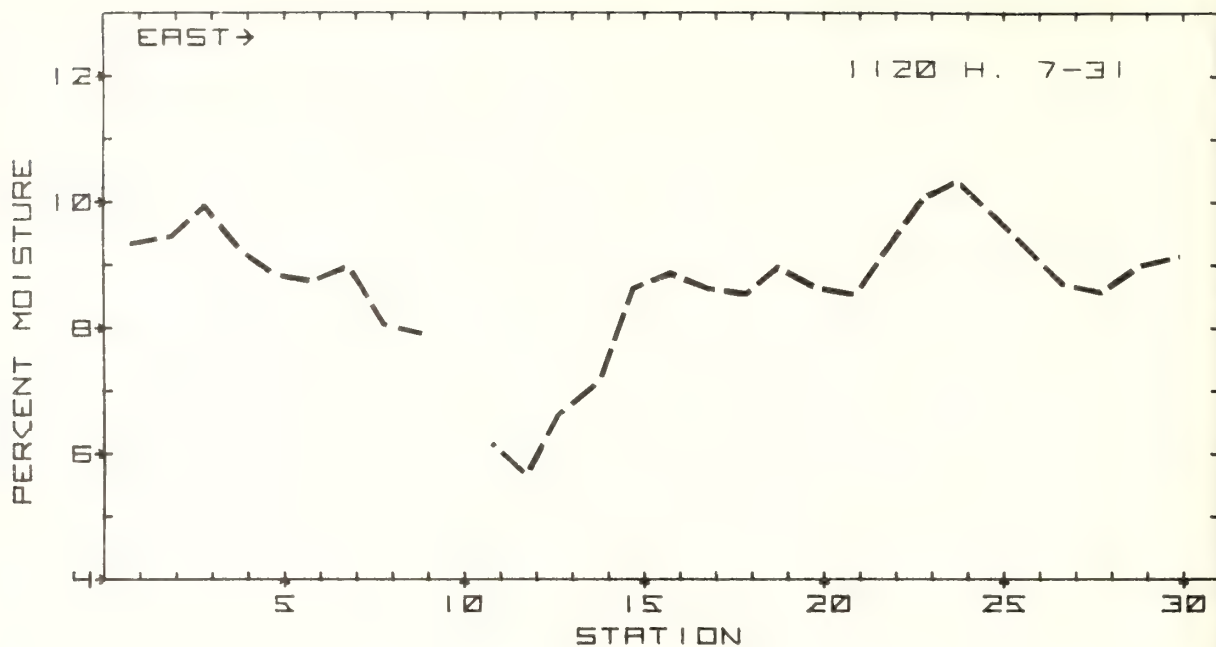


Figure 11 — Moisture content pattern for Transect 6 on July 31.

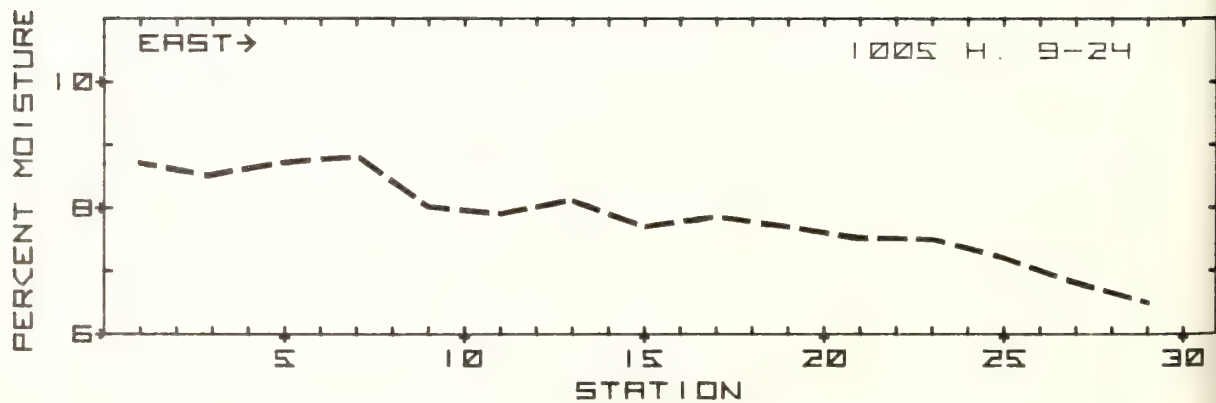


Figure 12 — Moisture content pattern for Transect 6 on September 24.

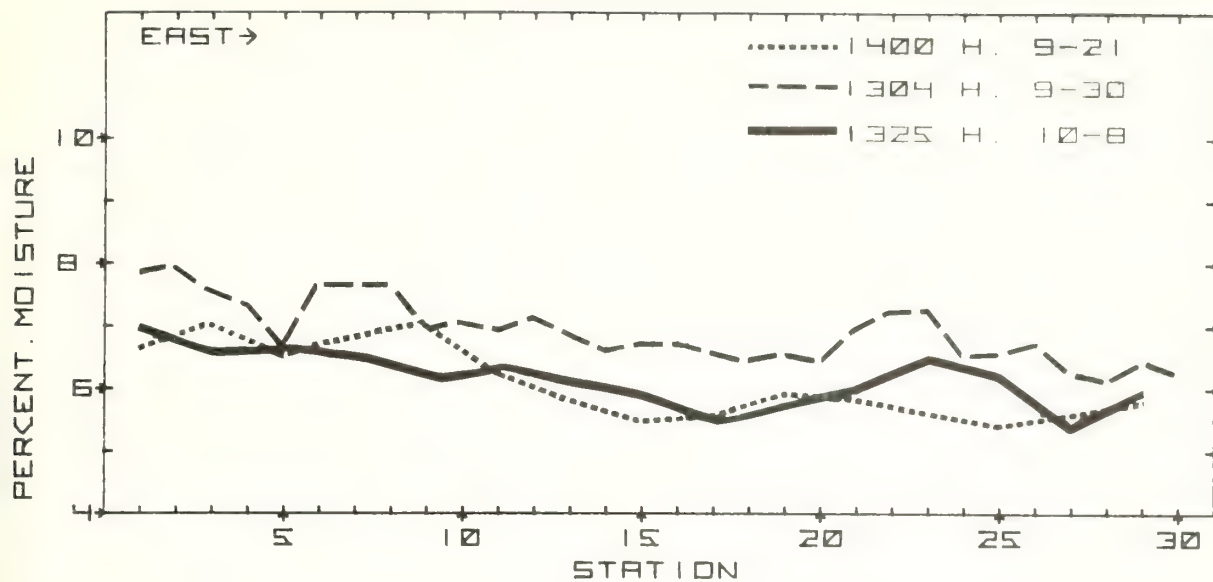


Figure 13 — Moisture content patterns for Transect 6 on September 21, September 30, and October 8.

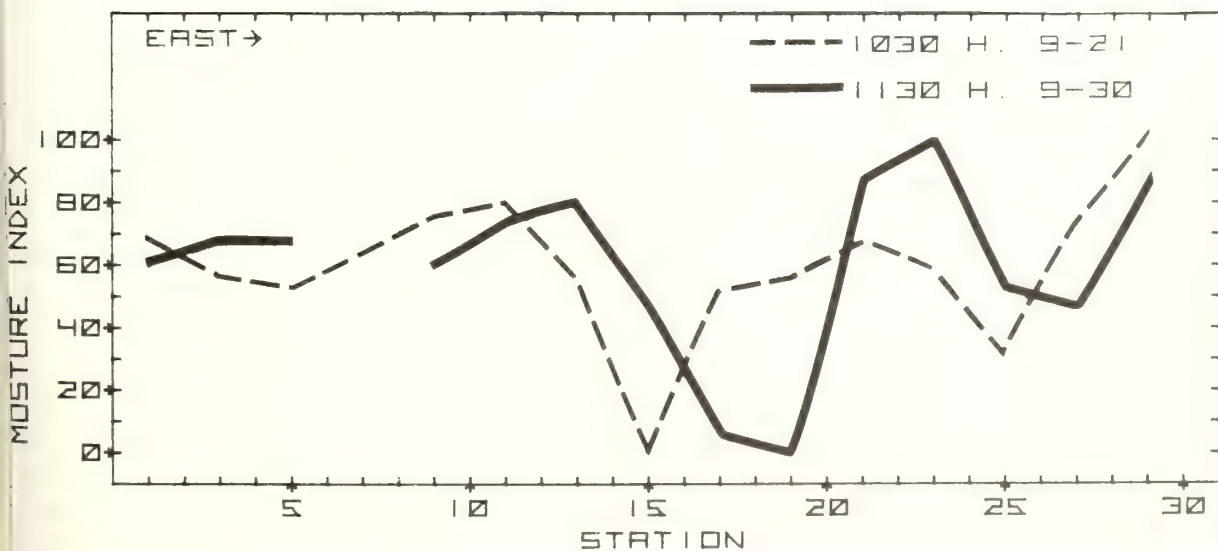


Figure 14 — Moisture indexes for Transect 3 on September 21 and 30.

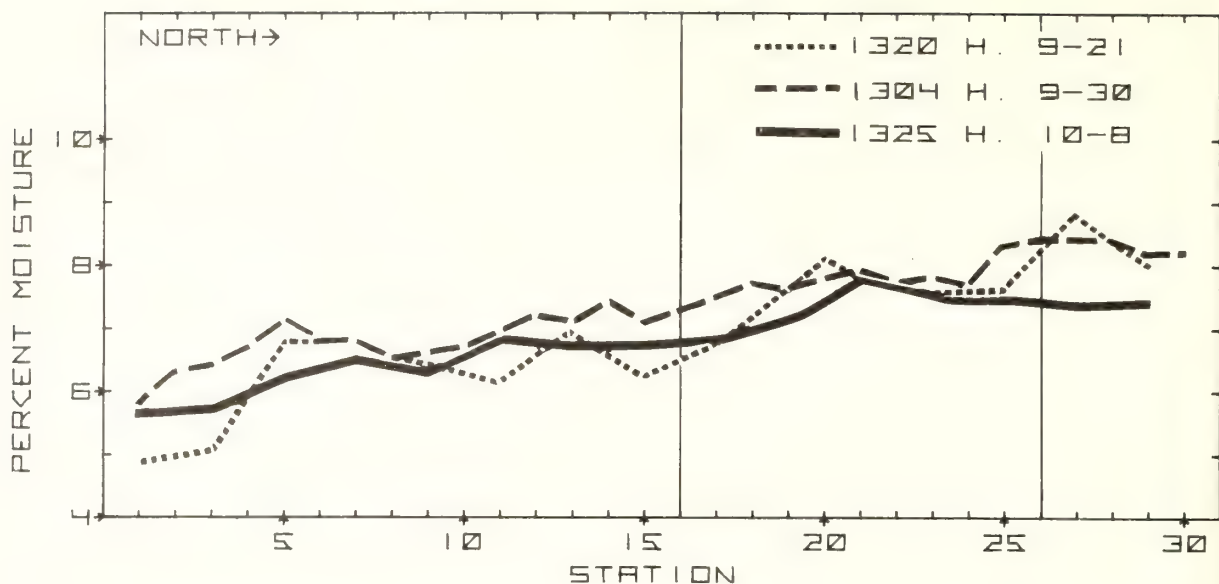


Figure 15 — Moisture content patterns for Transect 5 on September 21, September 30, and October 8.

CONCLUSIONS

This exploratory study demonstrates that variations in the moisture content of litter under ponderosa pine stands can be great enough within short horizontal distances to significantly affect the ignition and behavior of wildland fire. Work by Rothermel and Anderson (1966), for example, indicates that the range of moisture found for Transect 3 on July 21 will cause a variation in the rate of spread of about 21 percent for a no wind condition. Studies by Fons³ show that with a 6 mi/h wind the range in moisture for Transect 5 on July 29 would cause a 47 percent change in spread rate, and a 31 percent change would be caused by the moisture variation on Transect 6 on July 31. Because the probability of ignition increases rapidly with decreasing moisture content (Brown and Davis 1973), the likelihood of a firebrand starting a fire if falling on an area that has been exposed to solar radiation can be much greater than for continuously shaded areas. Changes in moisture as small as 0.5 percent are considered as significant in rate of fire spread, fire intensity, and fire ignition in fire danger rating (Deeming and others 1972).

The variations in fuel moisture are closely re-

lated to the amount and intensity of the solar radiation reaching the litter surface through openings in the crown canopy, and the effect that the openings have on cooling of the litter by radiation at night. Consequently, any influence affecting the radiation received or lost, such as latitude, time of day and year, stand characteristics, atmospheric conditions, and topographic configurations, will also affect the moisture variation patterns of the litter.

The data collected indicate that litter even briefly exposed to direct sunlight can become substantially lower in moisture than areas not exposed, and that the lower moisture level will persist after the litter is again shaded. The history of the exposure of an area to solar radiation is thus more important in determining the litter moisture at any given time than are the exposure conditions at that time.

Because of the exploratory nature of the study, the specific results probably apply directly only to the areas in which the data were collected. However, the strong relationships found between litter moisture and radiation heating and cooling have several important and widespread implications. The large spatial variations in surface fuel moisture found in the ponderosa pine stands are likely to exist in many other wildland vegetation types

³ Office report on file at the Forest Fire Laboratory, Riverside, California.

too. Deciduous forests, for example, have large seasonal variations in the degree of crown shading of surface fuels, and other types of coniferous forests have crown openings similar to those of ponderosa pine. Brush and other low-growing vegetation vary widely in crown density and in the amount of shading they provide to the surface litter and the protection they afford from nighttime cooling. High moisture content can result from dew formation in openings in the timber stand, and it is possible that the moisture in at least part of such openings may remain higher than surrounding areas throughout the day. These considerations can significantly affect prescribed burning procedures — such as burning slash in clearcut blocks. The moisture content of dead fuel is a key factor in the inception and behavior of wildland fire. Consequently radiation heating and cooling are important considerations in the design of moisture sampling procedures for studies of fire behavior and for the application of fire be-

havior information in fire danger rating, fire-fighting, prescribed fire, and other field activities where fuel moisture is significant.

The results of the study indicate a need for more sophisticated investigations of radiation heating and cooling in various wildland vegetative types and situations, with the object of developing area classification systems and measurement techniques whereby realistic estimates of fuel moisture can be made. Instrumentation for measuring solar radiation and radiation cooling in the wildland situation may need to be developed. However, measuring reflected light intensity from the litter with a photographic exposure meter, as was done nearly 50 years ago in this study, proved to be a highly effective and low-cost means of determining solar radiation intensity. In light of today's technology, development of means to measure solar radiation and radiation losses and determining the effects of radiation on wildland fuel moisture should not be formidable.

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1977. **Radiation effects on moisture variation in ponderosa pine litter.** USDA Forest Serv. Res. Paper PSW-126, 23 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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Oxford: 431.2:114.351 — 174.7 *Pinus ponderosa*.

Retrieval Terms: *Pinus ponderosa*; surface fuels; litter; fuel moisture content; solar radiation.

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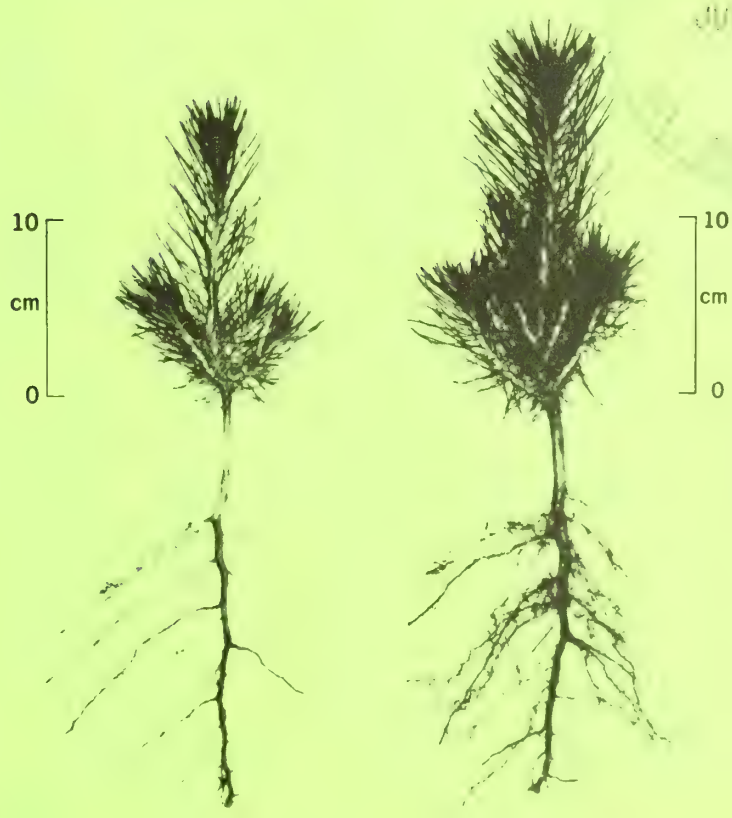
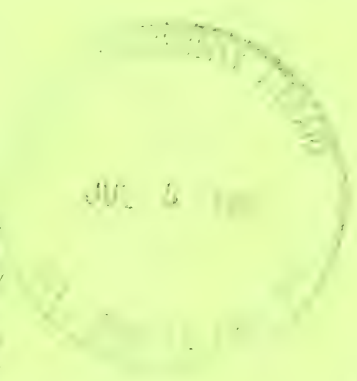
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PACIFIC SOUTHWEST Forest and Range Experiment Station

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Edaphic Interactions in First-Year Growth of California Ponderosa Pine

James L. Jenkinson



CONTENTS

	<i>Page</i>
Summary	1
Introduction	3
Methods	3
Stand Selection	3
Climate Evaluation	4
Test Procedures	6
Results	6
Relation of Seedling Growth to Seed	
Weight and Soil Fertility	7
Germination	7
Growth by Stand and Family	8
Discussion	13
Family Variation and Artificial Regeneration	13
Climatic Effects on Germination	13
Are There Edaphic Ecotypes?	14
Literature Cited	15

The Author

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SUMMARY

Jenkinson, James L.

1977. **Edaphic interactions in first-year growth of California ponderosa pine.** USDA Forest Serv. Res. Pap. PSW-127, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 174.7 *Pinus ponderosa*:181.34:181.525:165.52.

Retrieval Terms: *Pinus ponderosa*; genetic variation; germination; plant-soil relations; seedling growth.

California's commercially important conifers may be specifically adapted to local forest soils. To investigate such adaptation, natural stands were selected on one ultramafic, infertile soil and on a nearby fertile soil in each of four widely separated areas that typify mixed conifer forests and climates in the northern Sierra Nevada. Seeds were collected from 11 or more randomly distributed ponderosa pines in each stand.

Mean seed weight and speed of germination were determined for each family. Grouped by geographic area, germinants of every family were planted in a greenhouse in fertile and ultramafic soils obtained from the A horizon in the seed-parent stands. Growth for each family was evaluated on both test soils when the seedlings were 4 to 7 months old.

Germination rates of individual families varied widely for every stand, but this variation was not associated with the equally wide variation in family seed weight. In speed of germination, differences were large between areas and insignificant between paired stands. Thus, climate may have influenced inherent germination rate, but local soil type has not.

For three areas, seedling growth indicated no genetic differentiation between stands on contrasting soils. Even though overall growth was much greater on fertile than on ultramafic soil, mean top weights of seedlings never differed by more than 1 to 4 percent on either soil, and no stand $\times$ soil interaction was found. For the fourth area, offspring from the ultramafic stand were consistently smaller on both soils than offspring from the stand on fertile soil, apparently because of the significantly lighter seeds from trees on the ultramafic soil. For reasons I discuss, these results do not rule out edaphic ecotypes.

Seedling root growth in every soil was generally greater for families with large seeds. Seedling top growth was also tied to family seed weight, but the degree of association depended on both the growth trait measured and test soil fertility. Seedling heights on fertile soil were not related to seed weight. Variation in seedling top weight on fertile soil was weakly associated with variation in seed weight, whereas the association ranged from weak to strong on infertile soil. Also, the top weight—seed weight relation was moderate to strong only when top and root growth were highly correlated. When they were not, the relation of top weight to seed weight was weak.

Highly significant differences in seedling growth were found among families from every stand. Up to three-fourths of the families from each stand showed roughly the same ranking on ultramafic as on fertile soil. The other one-fourth showed significant differential responses to soil type — identified by comparing relative top growth performances that could not be explained by family seed weight. Apparently, wide variation in seedling growth of wind-pollinated families and large family $\times$ soil interactions are characteristic of the typical populations of California ponderosa pine in the Sierra Nevada.

For artificial regeneration, the results clearly imply that seed collections made in local tree seed zones need not be separated by or restricted to particular soils. Presently, the offspring of diverse stands appear to have comparable growth potentials on a given soil. The superior growth of certain families on both fertile and infertile soils, and of certain others on a single soil, suggest family (parent tree) selection for fast seedling growth on either a specific soil or an array of nutritionally different soils.

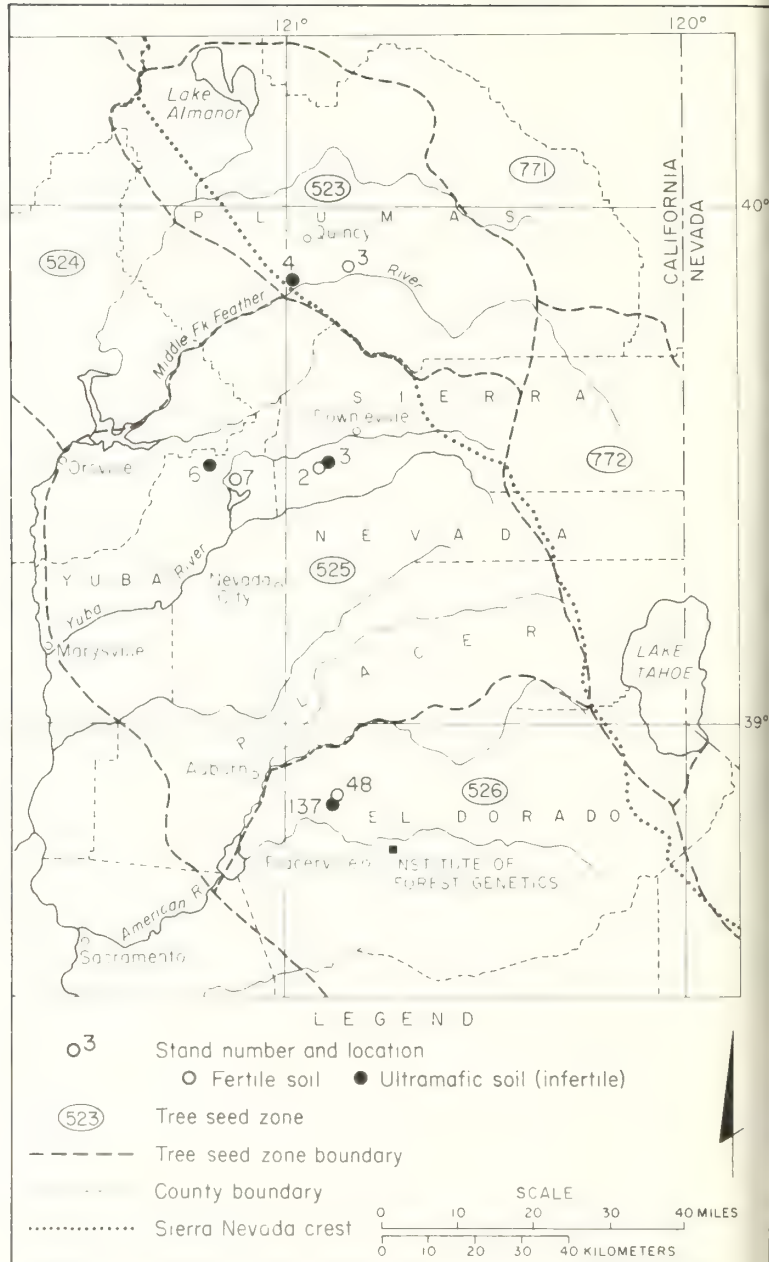


Figure 1 — To investigate local adaptation to soil fertility, natural stands of ponderosa pine were selected on an ultramafic soil and on a nearby fertile soil in four areas in the northern Sierra Nevada

Extraordinary edaphic variation is a common feature of California's major forest types. Sharp contrasts in tree growth and species composition between stands on adjacent soils are evident in most geographic areas and tree seed collection zones. Edaphic adaptation is a distinct possibility, yet few published studies have considered whether any widespread forest tree is specially adapted to local soils.

In the Coast Ranges, Klamath Mountains, and Sierra Nevada, ultramafic rocks are widely distributed (Rice 1957) and have weathered to form highly infertile soils. In the northern Sierra Nevada, these ultramafic soils lie in roughly parallel and discontinuous belts, crossing rivers and divides at elevations from 500 to 6600 ft (Calif. Div. Mines and Geol. 1971). Many of these soils fail to support the typical mixed conifer forest. Jeffrey pine (*Pinus jeffreyi* Grev. and Balf) — absent from most mixed conifer associations below 5500 ft — and incense-cedar (*Libocedrus decurrens* Torr.) characterize most ultramafic soils down to 3000 ft, and Digger pine (*P. sabiniana* Dougl.) characterizes them below that elevation (Griffin 1965). Ponderosa pine (*P. ponderosa* Laws.), which thrives abundantly in the mixed conifer forest, forms only occasional stands on ultramafic soils. Sugar pine (*P. lambertiana* Dougl.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) grow on them at middle and higher elevations, and white fir (*Abies concolor*

[Gord. and Glend.] Lindl.) grows on such soils at high elevations only. California black oak (*Quercus kelloggii* Newb.) is excluded from all ultramafic soils except those in the Cornutt series.

Only Digger pine has been adequately sampled for investigation of soil adaptation (Griffin 1965). Seedling growth performances of offspring from 17 stands, 5 of which were restricted to infertile serpentinite soil, were compared on one nutritionally sterile serpentinite and on one fertile forest soil. Though differences among stands were great, no general adaptation of the serpentinite progenies to serpentinite soil was indicated.

Stands of ponderosa pine, like those of Digger pine, survive and grow on ultramafic soils in a wide variety of climates. On such soils, trees are chronically subject to nutrient deficiencies of calcium, nitrogen, phosphorus, and potassium. If these trees are specially adapted to function in such circumstances, growth of their offspring on the local soil might reflect this adaptation when compared to the growth of offspring from trees on fertile soil. In an earlier study, the ability of ponderosa pine seedlings to take up calcium and grow on soils low in available calcium was much greater in some single-tree progenies than it was in others (Jenkinson 1974).

This paper reports a study of selected stands of ponderosa pine for specific adaptation to local forest soils.

METHODS

To investigate edaphic adaptation, seedling growth performances of wind-pollinated families from trees in stands on an ultramafic soil and on a nearby fertile soil were evaluated and compared on both soils. Germination rate and mean seed weight were determined for every family. The parent stands were characterized and their climates were evaluated.

Stand Selection

Two natural stands of ponderosa pine, one on ultramafic and one on fertile soil, were selected in each of four geographic areas in the northern Sierra Nevada (fig. 1; table 1). Three areas — the Yuba, Sierra, and Plumas — represent the mixed phase of the mixed conifer forest — ponderosa

and sugar pines, incense-cedar, Douglas-fir, white fir, California black oak — that dominates the Cascade-Sierra Nevada mountain chain in California (Griffin and Critchfield 1972). The Yuba and Sierra areas are at low and middle elevations in the zone of maximum rainfall on the western slope. The Plumas area is the coldest and most northerly, and lies in a transition zone between the east and west slopes of the Sierra Nevada. The fourth area — El Dorado — is the most southerly and typifies the warm, dry, low-elevation west-side-pine phase dominated by ponderosa pine.

Except for soil, the site factors for each pair of stands are similar. Differences between soils are primarily due to parent material. The ultramafic soils, in addition to being markedly deficient in nutrients (Jenkinson 1974), are comparatively shallow and rocky.

The stands on fertile soils are second growth

that was naturally regenerated after repeated logging of the virgin forest. They might be described as even-aged, although each includes several distinct age classes. The stands on ultramafic soil are all-aged, and contain trees in five or more widely separated, poorly defined classes. All stands are on gentle-to-moderate slopes of ridges, divides, or other uplands.

Climate Evaluation

Climates were evaluated from data recorded at 16 upland stations (U.S. Dep. Commer. 1964a, 1964b, 1970). The El Dorado, Yuba, and Sierra areas are points on the temperature gradient associated with elevation on the west slope of the Sierra Nevada. The Plumas area, though comparable to the Sierra in elevation, lies east of the main crest (fig. 1) in a continental climate. Daily fluctuations of air temperature in the Plumas area vary

Table 1 — Seed sources of ponderosa pine selected on fertile (F) and ultramafic, infertile (I) soils in four areas in the northern Sierra Nevada

Area (county), stand number, and locality	Soil series and parent material	Seed parents		
		Elevations	Ages	Arborescent associates ¹
		<i>Feet (meters)</i>	<i>Years</i>	
El Dorado:				
48 Garden Valley	Sites-like (F), marine	1920 to 1960 (585 to 597)	46 to 96	L, QuKe, QuCh
137 Johntown Creek	Henneke (I), serpentinite	1900 to 1950 (579 to 594)	85 to 217	S, LiDe
Yuba:				
7 Kennedy Ranch	Holland-like (F), granitic	2950 to 3000 (899 to 914)	43 to 58	L, AC, LiDe, QuKe, ArMz, S
6 Woodleaf	Dubakella (I), serpentinite	3050 to 3150 (930 to 960)	62 to 300	LiDe
Sierra:				
2 Gleason Spring	Lyonsville-like (F), volcanic	4640 to 4720 (1414 to 1439)	85 to 112	L, AC, PsMz, LiDe, QuKe
3 Brush Creek	a lithosol (I), slickentite	4560 to 4640 (1390 to 1414)	54 to 204	QuCh, PsMz, LiDe
Plumas:				
3 Spring Garden	Mariposa-like (F), marine	4840 to 4980 (1475 to 1518)	87 to 132	L, PsMz, LiDe, AC, QuKe
4 Rocky Point	Cornutt (I), peridotite	4900 to 5050 (1494 to 1539)	78 to 235	LiDe, L. PsMz, AC, QuKe, QuGaSe, J

¹ L: *Pinus lambertiana* Dougl.
S: *P. sabiniana* Dougl.
J: *P. jeffreyi* Grev. & Balf.
AC: *Abies concolor* (Gord. & Glend.) Lindl.
LiDe: *Libocedrus decurrens* Torr.

PsMz: *Pseudotsuga menziesii* (Mirb.) Franco
ArMz: *Arbutus menziesii* Pursh
QuKe: *Quercus kelloggii* Newb.
QuCh: *Q. chrysolepis* Liebm.
QuGaSe: *Q. garryana* var. *semota* Jeps.

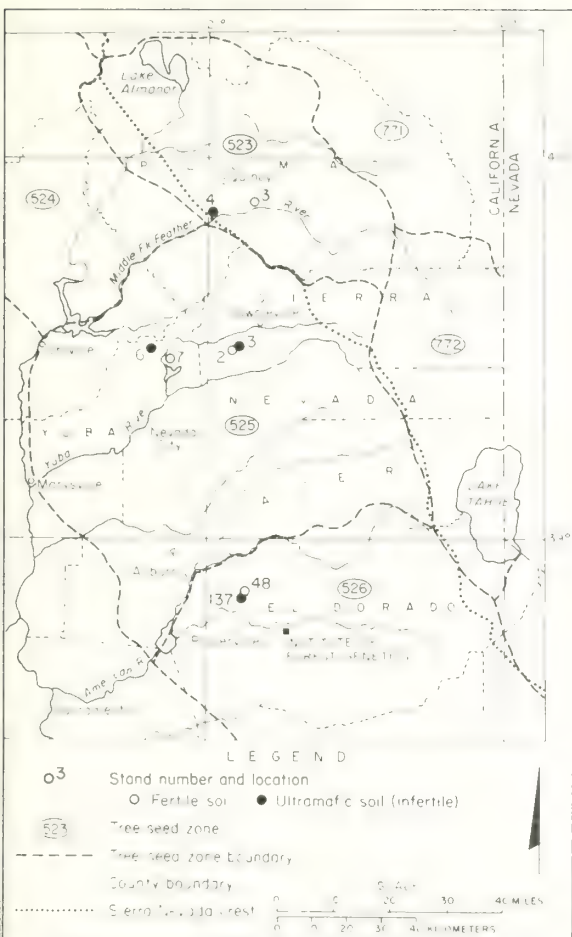


Figure 1 — To investigate local adaptation to soil fertility, natural stands of ponderosa pine were selected on an ultramafic soil and on a nearby fertile soil in four areas in the northern Sierra Nevada.

from 30 percent greater in winter to 80 percent greater in summer than fluctuations on the west slope (fig. 2).

The seasonal sum of air temperatures that support growth activity is greatest for the El Dorado area and least for the Plumas, where mean daily minimum temperatures are lowest and the winters are coldest. Growing seasons, estimated by summing days with a mean daily minimum above 0° C, are 12, 11, and 8 months in the El Dorado, Yuba, and Sierra areas, and roughly 5 months in the Plumas. The expected freeze-free periods, when minimum temperatures are consistently above -2° C, are 310, 265, 200, and 65 to 120 days (fig. 2).

Snowfall is 5 to 7 ft in the Plumas, 10 to 12 ft in the Sierra, and 4 to 6 ft in the Yuba area. The El Dorado area is below snowline.

No significant rain falls in any area during July

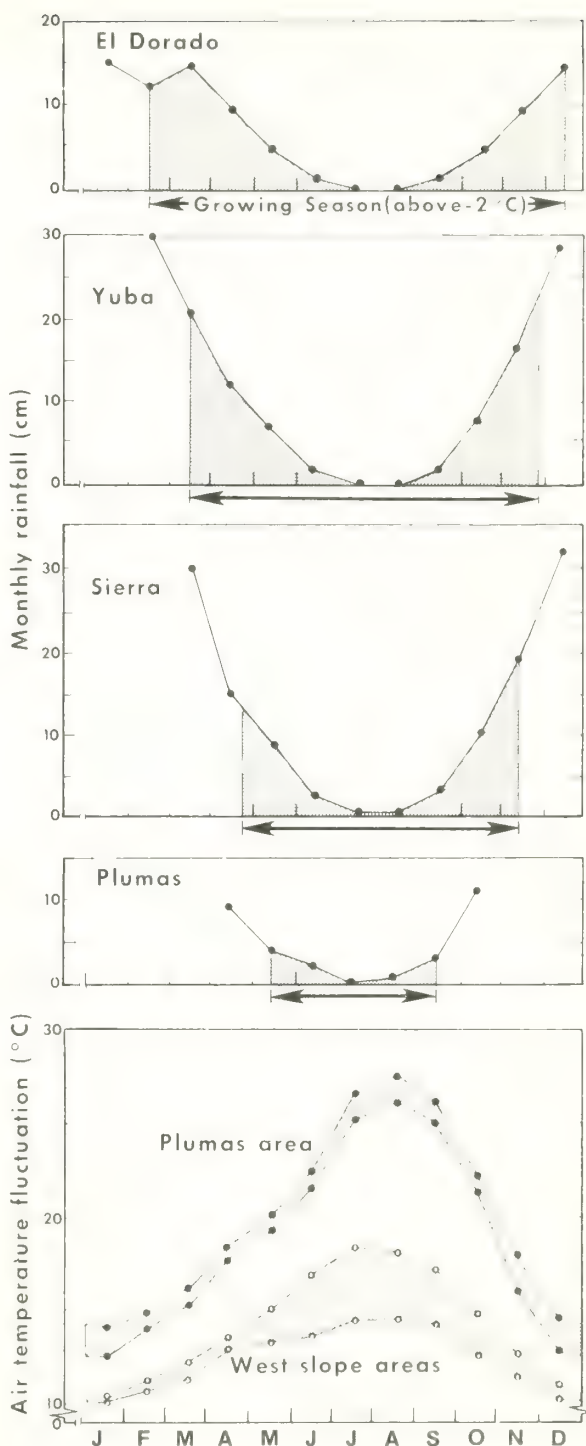


Figure 2 — Climate differs markedly for ponderosa pine west and east of the main Sierra crest: Above, significant spring rainfall overlaps the freeze-free period in the western El Dorado, Yuba, and Sierra areas, but not in the eastern Plumas area. Below, day-night air temperature differences in the Plumas area exceed those on the western slope. (The two curves which delimit each shaded zone are the smallest and largest mean daily fluctuations determined for local stations.)

and August, but the summer drought is most severe in the El Dorado area (*fig. 2*). The Plumas area resembles the dry El Dorado in late spring and the wet Yuba-Sierra zone in early fall. In spring (April-June), twice as much rain falls in both the Yuba and Sierra areas as in the Plumas. In fall (September-November), the El Dorado rainfall is usually just half that of the other areas.

In every area the higher plant water stresses probably develop on the ultramafic soil. Available water capacities are lower in these soils, and their sparse vegetation permits greater insolation and evaporative water loss.

Test Procedures

Seed collections were made in all areas in a good crop year. From 35 to 50 cones were picked from the upper crown of each of 12 randomly distributed trees in each stand, except in Sierra 2 (on fertile soil) where 11 trees were sampled. In the Yuba stands a larger collection, noted as Yuba II, was made three years later, when 18 trees — including 13 new ones — were sampled in each stand. Seeds were extracted from sun-dried cones, cleaned, and stored at 1° to 2° C.

Germination and seedling growth of the individual families were evaluated in a series of five tests at the U.S. Forest Service Institute of Forest Genetics, near Placerville (*fig. 1*).

The mean seed weight for each family was determined from the air-dry weight of 400 full seeds. These seeds were then stratified 60 days at 1° to 2° C in moist, Captan-treated sand, and germinated 14 days at 20° to 25° C on filter paper over wet sand in Petri dishes. During the first 5 days of germination, germinants of each family were stored at 5° C to slow their radicle growth and hold them in similar stages of development for initiating the seedling growth test.

The experimental design for the germination test was a randomized block with four replications — 100 seeds per dish and 4 dishes per family. Seeds were counted as germinated when the radicle emerged 2 mm. After 14 days, the remaining

seeds were cut to verify soundness. To evaluate peak germination rates, the maximum mean daily germination was determined for each family (Czabator 1962).

By area, families from both stands were grown on both of the native soils in a greenhouse. The experimental design was a split-plot, randomized block with eight replications. Native soils were the major plots and individual families were the minor plots. Soil was dug from the A horizon in each stand, screened to 5 mm, blended, and transferred to polyethylene-lined containers measuring 9.5 cm square and 30 cm deep. Each container was planted with five germinants of a single family. Forty germinants per family — 8 five-seedling plots — were planted on each soil. The planting of most families was completed the same day, with germinants stored from 0 to 4 days. All plantings were first watered with a Captan suspension to control damping-off fungi, and thereafter with distilled water to avoid any addition of nutrients.

Seedlings were grown under a 16-hour photoperiod and harvested after 4 months (El Dorado), 5.5 months (Yuba, Sierra, Plumas), and 7 months (Yuba II). Individual seedling heights were measured from cotyledon scar to shoot apex, and tops were cut from roots at the cotyledon scar. The oven-dry (65° C) weight of each top and the total oven-dry root weight per container were recorded.

By area, the data for each seedling growth trait and for peak germination rate were subjected to analyses of variance. Data analyses included linear regressions of family growth traits and seed weight. Because the growth and seed weight relations were similar for offspring of stands evaluated on the same soil, coefficients of determination (r^2) were calculated on pooled data for each soil. Because some variation in growth was associated with seed weight, top weights for the individual families were adjusted to remove this effect and the adjusted data were analyzed. Significant differences among family means were identified by using Duncan's multiple range test and least significant difference procedures (Steel and Torrie 1960).

RESULTS

In the four areas sampled, mean seed weights of individual families from trees on ultramafic and fertile soils offered little evidence of stand adapta-

tion to either local climate or local soil. Differences in mean seed weight between the El Dorado, Yuba, Sierra, and Plumas areas were no

significant (5 percent level). Trees on ultramafic soil in the Yuba area, apparently reflecting their nutrient-deficient and water-stressed condition, consistently produced smaller seeds than trees on fertile soil (table 2). In each of the other areas, however, the difference in seed weight between stands was not significant.

Mean seed weights of individual families varied widely, with roughly two-fold differences in most stands (table 2). In the higher-elevation Sierra and Plumas areas, but not El Dorado and Yuba, the variance of family seed weights was significantly less for families from trees on ultramafic soil than for those from trees on fertile soil.

Relation of Seedling Growth to Seed Weight and Soil Fertility

Among ponderosa pine families from every area, some variation in seedling growth was associated with variation in seed weight (table 3). The relation to seed weight varied with the growth trait measured and with fertility of the test soil. On fertile soils, the mean heights of individual

families were not related to seed weight. On ultramafic soils from the El Dorado and Yuba areas, but not the Sierra and Plumas, several families with light seeds did produce shorter seedlings.

Family root weight was always moderately to strongly associated with seed weight. Family top weight, however, was not consistently related to seed weight, but apparently was influenced by it through the relation to root growth. Thus, when top weight was strongly correlated with root weight, it was also moderately to strongly related to seed weight ($r^2 = 0.41$ to 0.72). When top weight was not strongly correlated with root weight, it was weakly related to seed weight ($r^2 = 0.22$ to 0.25). In four of the five tests, the weaker relation between top weight and seed weight was found on the fertile soil.

Germination

After 4 days, germination of seeds from trees in the Yuba and Plumas areas was from 13 to 27 times greater than that of seeds from the El Dorado and Sierra areas (table 2). Such differ-

Table 2 — Seed weights and 4-day germination of ponderosa pine families from stands on fertile (F) and infertile (I) soils

Area and stand	Seed weight		4-day germination	
	Family average ¹	Range of family means	Family average ¹	Range of family means
	———— Mg —————		———— Percent ————	
El Dorado:				
48 (F)	51	30 to 64	2.6	0 to 16
137 (I)	54	40 to 70	3.5	0 to 16
Yuba:				
7 (F)	60 a	40 to 88	79	62 to 95
6 (I)	44 b	32 to 63	83	39 to 99
Yuba II:				
7 (F)	53 a	41 to 66	76	34 to 98
6 (I)	42 b	27 to 53	78	37 to 97
Sierra:				
2 (F)	53	32 to 85	5.5	0 to 21
3 (I)	46	38 to 53	5.6	0 to 35
Plumas:				
3 (F)	52	35 to 65	78	48 to 95
4 (I)	47	43 to 58	67	33 to 98

¹For an area, means followed by unlike letters differ significantly at the 5 percent level.

Table 3 — Coefficients of determination (r^2) for seedling growth traits and seed weight of ponderosa pine families tested on fertile (F) and infertile (I) soils¹

Area and test soil	r^2 for ...				
	Seedling growth trait on seed weight			Height on top weight	Top weight on root weight
	Height	Top weight	Root weight		
El Dorado:					
Sites-like (F)	0.00	0.24*	0.50**	0.39**	0.54**
Henneke (I)	.55**	.64**	.36**	.70**	.71**
Yuba:					
Holland-like (F)	.00	.25**	.59**	.37**	.30**
Dubakella (I)	.24*	.70**	.90**	.44**	.80**
Yuba II:					
Holland-like (F)	.14*	.41**	.67**	.62**	.40**
Dubakella (I)	.42**	.72**	.81**	.60**	.72**
Sierra:					
Lyonsville-like (F)	.00	.58**	.74**	.17	.73**
a lithosol (I)	.13	.22*	.70**	.18*	.42**
Plumas:					
Mariposa-like (F)	.00	.22*	.70**	.47**	.22*
Cornutt (I)	.13	.41**	.70**	.72**	.71**

¹Family means in regression were 23 for Sierra, 24 each for El Dorado, Yuba, and Plumas, and 36 for Yuba II. Asterisks designate values for r^2 significant at the 5 (*) and 1 (**) percent levels.

ences between areas were negligible at 14 days, when total germination was 91 to 99 percent.

Edaphic adaptation was not evident in speed of germination. Offspring from stands on fertile and infertile soils in the same area always had similar peak germination rates (*fig. 3*).

Without exception, the peak germination rate varied widely for individual families from the same stand (*fig. 3*). In one area, variation in peak rate was greater for families from trees on ultramafic soil than for those from trees on fertile soil: Family means ranged from 9 to 32 percent per day in Plumas stand 4, against 15 to 28 in Plumas stand 3. As with other areas, however, most of the families differed only in rate of germination, and with few exceptions had from 95 to 100 percent germination at 14 days.

Germination rates of families were independent of seed weight, except that a number of small-seed Yuba families germinated with exceptional speed ($r^2 = -0.18$).

Growth by Stand and Family

Overall, top growth of seedlings on fertile soil exceeded the growth on ultramafic soil by 50 percent or more, although even the fertile soils were somewhat deficient in nitrogen.

For the El Dorado, Sierra, and Plumas areas, analyses of the growth of offspring from both stands on both native soils indicated no genetic differentiation between the parent stands (*table 4*). There was no difference in any growth trait between stand offspring, and there was no differential response of stand offspring to soil fertility (stand $\times$ soil interaction). Average top weights of seedlings from the two stands — whether compared on ultramafic or on fertile soil — never differed by more than 1 to 4 percent (*fig. 4*). For the Yuba area, seedlings from the ultramafic stand were significantly smaller on both soil types, apparently because of the smaller seeds from parents on the ultramafic soil (*table 2*).

Although offspring from paired stands generally showed equal growth, large and highly significant differences in seedling growth were found among families from different trees in every stand (table 4, families/stand). On fertile soil, for example, El Dorado family 48-4 had inherently better growth than 3, 13, 11, and 5, and families 6 and 12 were superior to 5 and 2 (fig. 4). Such inherent

family differences in seedling growth were just as evident on ultramafic soil, in comparisons of families with equivalent seed weights. Top growth for individual families ranged from below 80 to more than 120 percent of the stand mean, whether the seedlings were grown on ultramafic or on fertile soil.

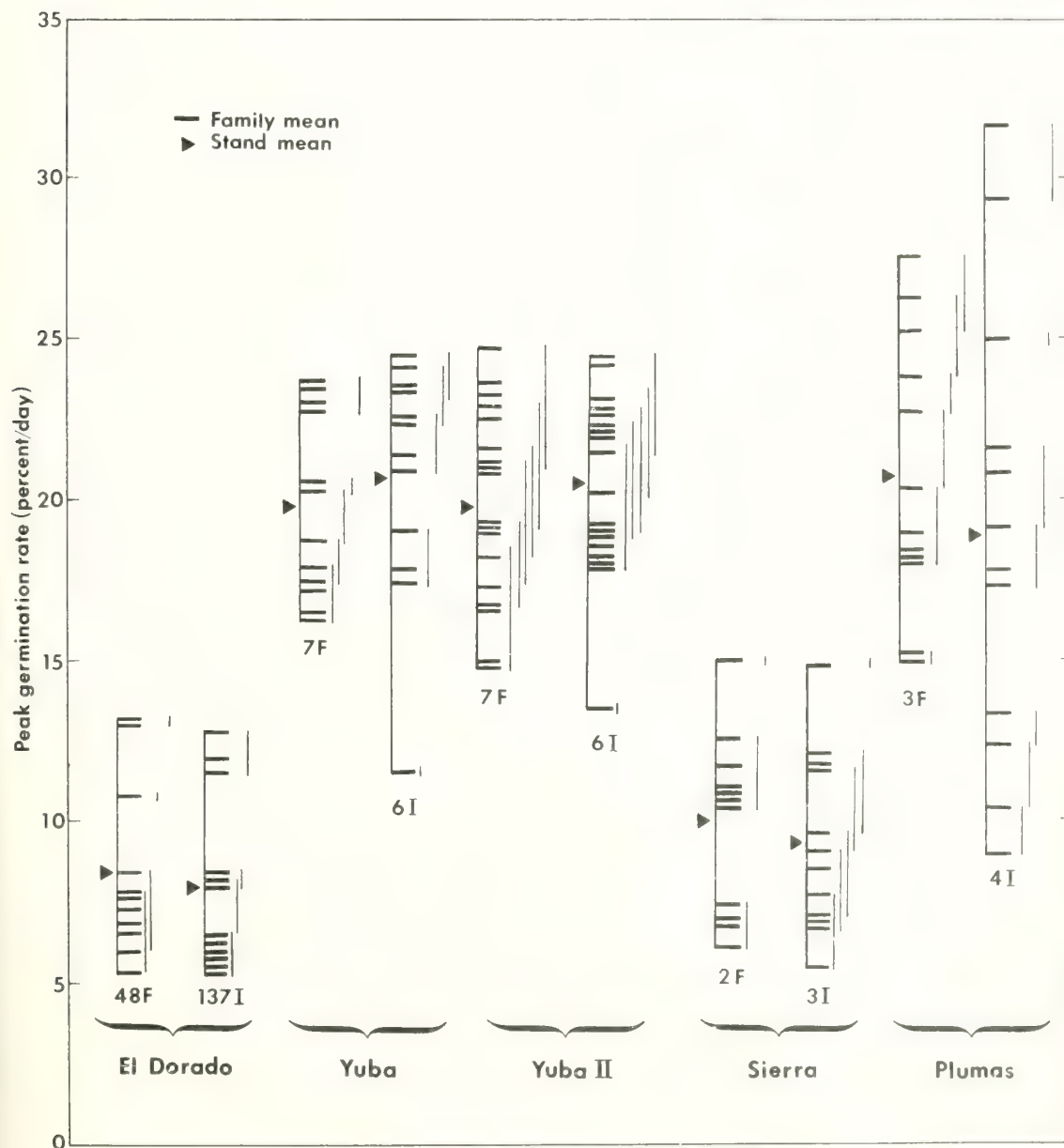


Figure 3—Speed of germination for ponderosa pine differed between areas and among families from the same stand, but not between paired stands. Seeds tested were from trees in stands on fertile (F) and infertile (I) soils, and represent two crop years in the Yuba area. Family means not common to a bar differ significantly at the 5 percent level

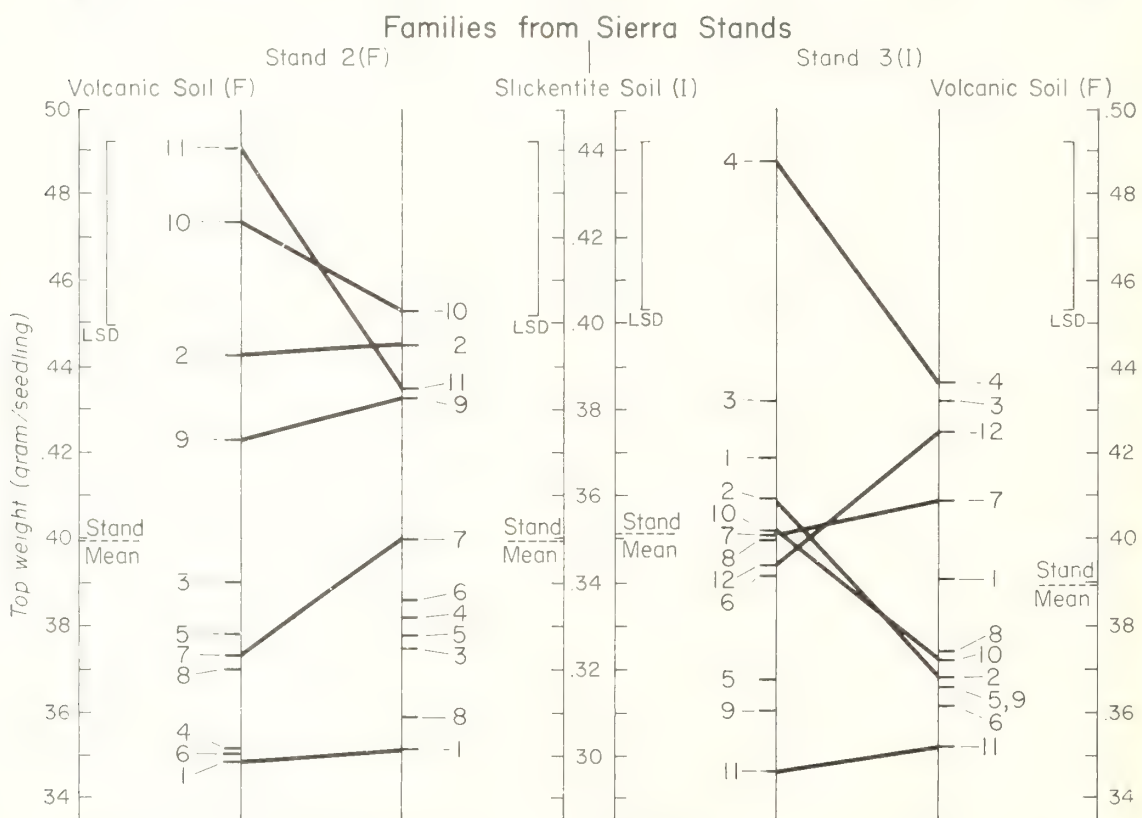
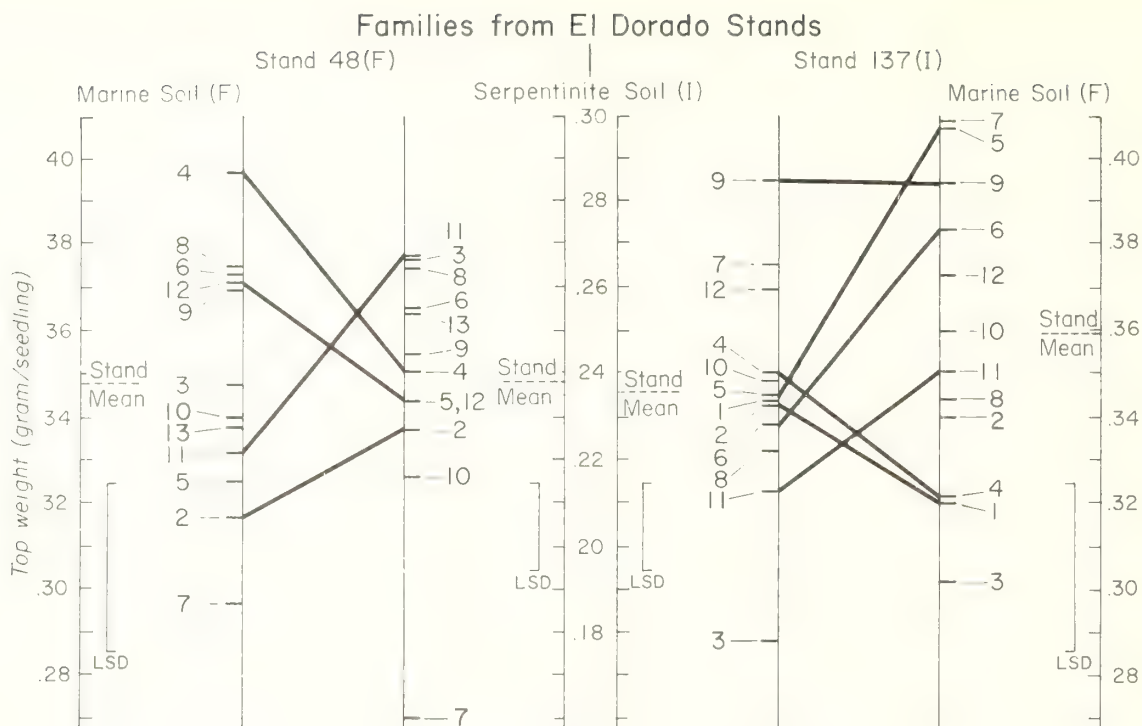
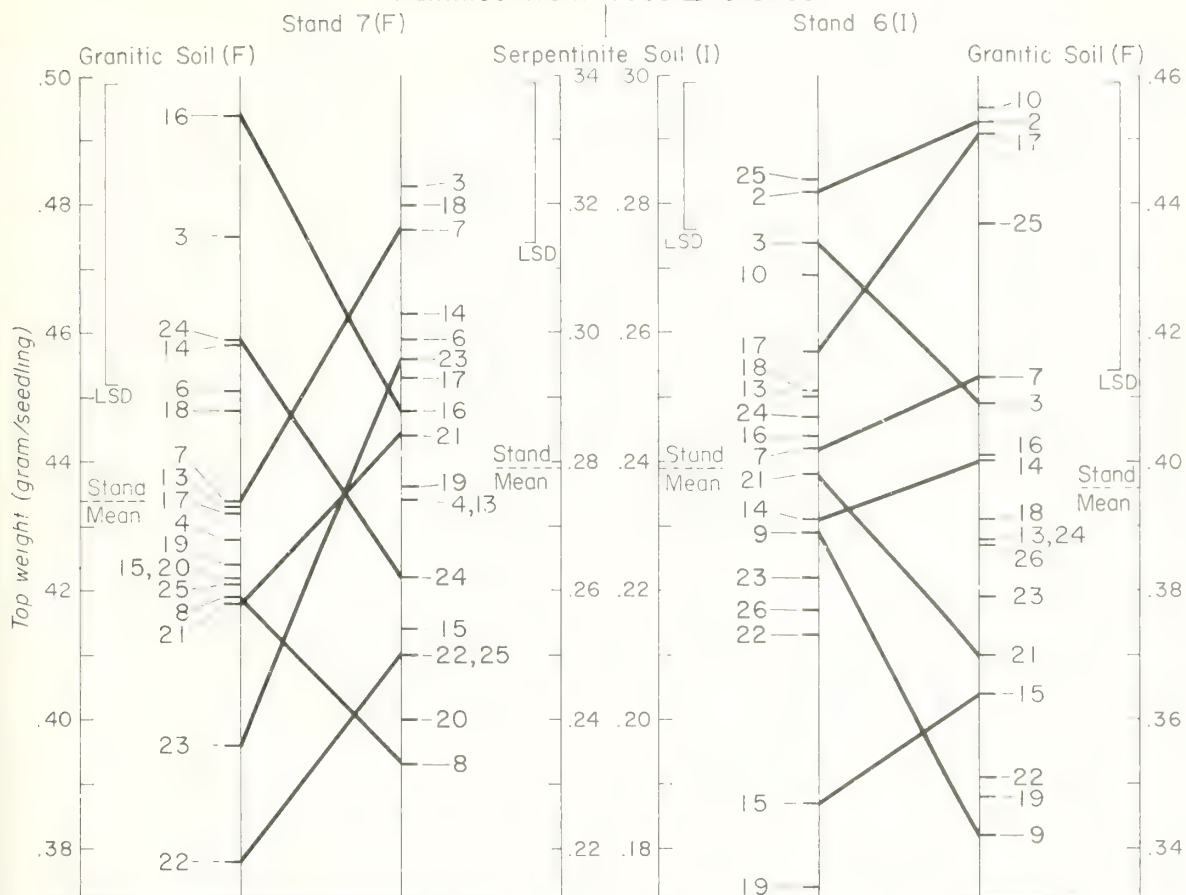
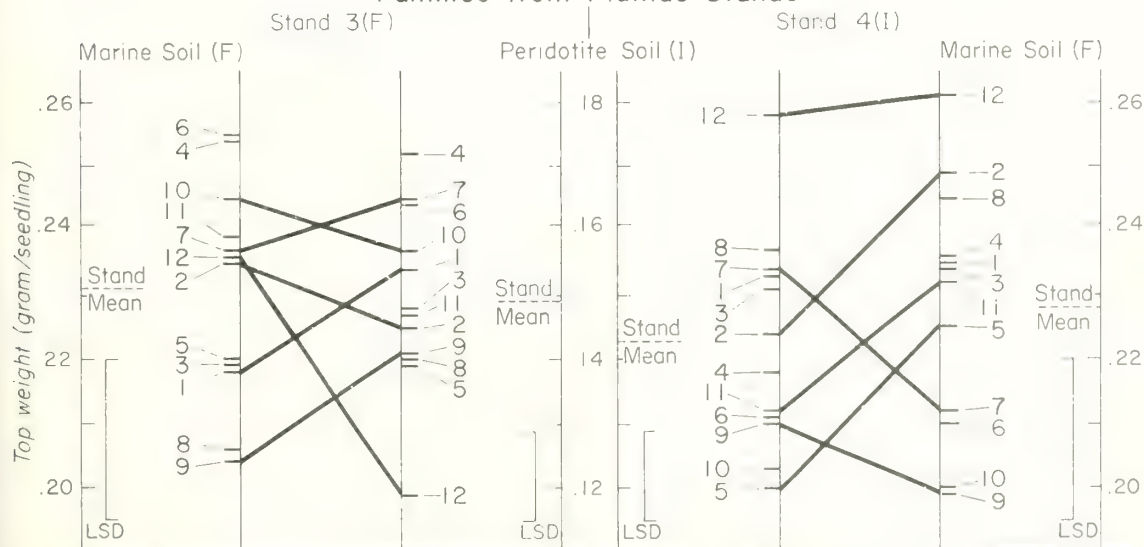


Figure 4—Seedling growth of ponderosa pine on fertile (F) and infertile (I) soils indicated little or no genetic differentiation between parent stands in any area, but varied widely among families of every stand and

Families from Yuba II Stands



Families from Plumas Stands



demonstrated large family X soil interactions. On each soil, family means separated by the least significant difference (LSD) differ significantly at the 5 percent level. Diagonal lines identify groups of families that show inherent differential response to soil type.

Table 4 — Significance of variation associated with stands, families, and soil interaction in seedling growth of ponderosa pine tested on fertile and infertile soils¹

Area and source of variation	Seedling growth trait			
	Height	Top weight	Top weight adjusted ²	Root weight
El Dorado:				
Stands	ns	ns	ns	ns
Stand × soil	ns	ns	ns	ns
Families/stand	***	***	***	***
Families/stand × soil	***	*	**	ns
Yuba:				
Stands	ns	***	***	***
Stand × soil	ns	***	***	***
Families/stand	***	***	***	***
Families/stand × soil	ns	***	ns	***
Yuba II:				
Stands	***	***	***	***
Stand × soil	ns	ns	ns	ns
Families/stand	***	***	***	***
Families/stand × soil	ns	**	**	ns
Sierra:				
Stands	ns	ns	ns	ns
Stand × soil	ns	ns	ns	ns
Families/stand	***	***	***	***
Families/stand × soil	ns	ns	ns	ns
Plumas:				
Stands	ns	ns	ns	ns
Stand × soil	ns	ns	ns	ns
Families/stand	***	***	***	***
Families/stand × soil	***	*	**	ns

¹Variation was significant at the 10 (*), 5 (**), and 1 (***) percent levels, or was not significant (ns).

²Effect of family seed weight was removed before analysis.

Many families displayed the same rankings on both soils (*fig. 4*). Thus, seedling growth was consistently good for some families — e.g., El Dorado 48-6 and 8, 137-7 and 9; Yuba II 7-3 and 14, 6-2 and 25; Sierra 2-2 and 10, 3-3 and 4; Plumas 3-4 and 6, 4-8 and 12 — and consistently poor for others — e.g., El Dorado 48-7 and 137-3; Yuba II 7-8 and 22, 6-15 and 19; Sierra 2-1 and 8, 3-9 and 11; Plumas 3-8 and 9, 4-9 and 10.

Strong family × soil interactions were indicated for seedling height, top weight, or both for families from the El Dorado, Yuba, and Plumas areas (*table 4*). In fact, at least one-fourth of the families from every stand — including the Sierra

stands — showed significant changes in their relative growth performances on ultramafic and fertile soils (*fig. 4*). In El Dorado stand 137, for example, families 4, 5, 1, and 6 showed average top growth on serpentinite soil, but 5 and 6 were superior to 4 and 1 on marine soil. In Yuba II stand 7, family 16 outperformed 7, 20, and 21 on granitic soil, and 24 topped 23 and 22; but on serpentinite soil, 7 outperformed 16 and 21, which in turn surpassed 20, and 23 topped 24 and 22. These and other differential responses to soil were identified through relative growth performances that could not be explained by family differences in seed weight.

DISCUSSION

In the northern Sierra Nevada, wind-pollinated families of ponderosa pine vary widely in first-year seedling growth. The differences among progenies of randomly selected trees in natural stands are invariably great, regardless of the local soil and climate.

Family Variation and Artificial Regeneration

The patterns of variation have several implications for tree seed collection and reforestation programs. For every seed parent stand selected, we can expect that three-fourths of the families will show roughly the same relative rankings for seedling growth on fertile as on infertile soil. One-sixth of the families will produce superior seedlings on both soil types, and the others will produce mostly average or inferior seedlings.

One-fourth of the families from every selected stand will show marked differential responses to soil nutrient status. Family $\times$ soil interactions apparently characterize California ponderosa pine, and may prove to be typical of other widespread forest trees. Investigations of both conifers and hardwoods have found interactions between families, clones, or provenances, and soils of differing nutritional status (Brown 1970, Cunningham 1971, Curlin 1967, Giertych 1970, Goddard and others 1976, Jahromi and others 1976, Jenkinson 1974, Ohba and others 1965, Pritchett and Goddard 1967, Roberds and others 1976, Zobel and Roberds 1970).

Because similar distributions of family growth potentials may be expected from stands growing on completely different soils, the tree seed collection zones for reforestation (Buck and others 1970) need not be subdivided by soil type. The base level program for ensuring native genetic variability in planting stock (Kitzmilller 1976) — pooled seed collections from one or more trees in each of 20 widely distributed stands in a particular zone — should normally retain the distribution of seedling growth response, or adaptability, found within each zone sampled in my study (fig. 1).

The magnitudes of the genetic differences in family performance strongly suggest that parent trees can be selected for fast seedling growth on either a wide range of nutritionally different soils or a specific soil. Selected ponderosa pines might be profitably screened for both broad and specific

edaphic adaptation by growing their offspring on typically diverse soil series within the native climatic environment, or the appropriate tree seed zone.

Optimizing the seedling culture regime greatly diminishes the effects of family seed weight on first-year growth, an outcome desired in any progeny test. Top growth of seedlings from individual families in the present study was related very weakly or not at all to seed weight when soil nutrients were in adequate supply, but there were appreciable effects on infertile soil. In forest tree nurseries and greenhouses where water and nutrients are properly supplied and the growing season is six months or longer, the influence of family seed weight on seedling top growth is always negligible (Brown and Goddard 1959, Hanover and Barnes 1963, Hanover and Reicosky 1972, Jenkinson 1975, Morgenstern 1969, Stonecypher and others 1966). In less favorable environments with short growing seasons or summer drought, seed effects may persist (Morgenstern 1969), even up to five years for ponderosa and Jeffrey pine grown and outplanted in the Plumas area (Fowells 1953).

Climatic Effects on Germination

The rapid germination of seeds from most trees in the Plumas stands (fig. 3) may reflect the presence of selective climatic forces. In this climatic and vegetational transition zone between the east and west slopes, the onset of the freeze-free period practically coincides with that of the summer drought (fig. 2). The brief time available for germination and radicle elongation should therefore favor rapid germinators and discriminate against slow ones. Here, as for ponderosa pine in the Southwest, late and slow germinators produce seedlings that almost certainly are more subject to high water stress and drought kill (Larson 1961, 1963), and to frost heaving (Heidmann 1976).

Although families from the stand on fertile soil were all fast germinators, 4 of 12 from the ultramafic stand 9 miles west were comparatively slow. Persistence of slower germinators in a stand so near the main Sierra crest suggests the influence of west-slope climate. A topographic conduit for such influence exists, as the ultramafic population rims the canyon of the Feather River Middle Fork, which cuts completely through the Sierra Nevada (fig. 1).

As native climate may explain the rapid germination of most Plumas families, it may also explain the comparatively slow germination of seeds from all four stands in the El Dorado and Sierra areas (fig. 3). Germination and growth conditions are favorable for a much longer time on the west slope than in the Plumas area, because the overlaps of spring rain and freeze-free period are much greater (fig. 2). In these milder environments, occasional hard freezes ranging from -3° to -12° C are likely in spring (U.S. Dep. Commer. 1964, 1970), and early or fast germinators may be subject to frost heave and freezing. A single exposure to night temperature below -6° C is lethal for 1-week-old seedlings of ponderosa pine from the east slope of the Cascade Range in southern Oregon (Cochran and Berntsen 1973), and presumably this cold exposure also kills west-slope seedlings.

More difficult to explain are the germination rates of seeds from the Yuba stands, which are just as rapid as those of the Plumas. Both Yuba stands are on uplands adjacent to the canyon carved by the North Yuba River (fig. 1), and may be disposed to cold air flows. The river breaches the Sierra crest (7000 to 8500 ft) at elevations of 3900 to 4900 ft, draining the high country fronting the Sierra Valley, and snow in the Yuba stands often melts late in spring. Thus, continental-climate influence may reach the Yuba area, and drought may quickly follow onset of the freeze-free period. Although near the same canyon, the Sierra stands probably escape this influence, as they are 1800 ft above the river and on south slopes in another drainage.

Are There Edaphic Ecotypes?

The growth of ponderosa pine seedlings on ultramafic and fertile soils collected in the seed parent stands revealed no clear stand adaptation to soil fertility. In the Yuba test, seedlings from trees in the serpentinite stand were consistently smaller on both native soils than seedlings from the nearby stand on fertile soil. This result was also found in Digger pine, when offspring from trees on serpentinite soil grew poorest on that soil while offspring native to the closest nonserpentinite stand grew best (Griffin 1965). On both of these serpentinite collection sites, the understory varied from sparse to none. In such hostile circumstances, the lower nutrient and water demand

of slow-growing seedlings may occasionally favor their survival.

In the El Dorado, Sierra, and Plumas tests, growth of offspring from ponderosa stands on ultramafic and fertile soils was the same on ultramafic soil, and also on fertile soil. There are two possible explanations for these results:

- Edaphic ecotypes do not exist in ponderosa pine because soil nutrient status is not an important selective factor, or because gene migration prevents ecotype formation.
- Edaphic ecotypes do exist, but they were not demonstrated because off-site pollen — in wind-pollinated offspring — masks adaptation of the seed parents, or because adaptation is not expressed in early seedling growth.

Studies in Scots pine (*P. sylvestris* L.) and Norway spruce (*Picea abies* [L.] Karst.) show that extensive gene flow through pollen dispersion is characteristic of widely distributed conifers (Koski 1970). Nonlocal pollen of those species in Finland accounts for more than 60 percent of the pollination in near-pure stands, a condition that may also hold for ponderosa pine. Soil type boundaries do not restrict pollen flight, and the distance from the center of any sampled ultramafic stand to stands on more fertile soil varies from less than 0.3 to 1 mile.

Adaptation to infertile and arid soils may be reflected not in first-year growth of seedlings, but in the relative ability of the seedlings to continue growth in subsequent growing seasons. Adaptation to ultramafic soils in particular requires an ability to function indefinitely while subjected to chronic nutrient deficiencies and long periods of high water stress. Differential survival and growth under severe edaphic stress may then become evident in later years. This interpretation explains the eventual better growth of seedlings from ultramafic compared to nonultramafic sources of lodgepole pine (*P. contorta* Dougl.) outplanted on ultramafic soil (Kruckeberg 1967). Growth on the planting site was the same for all sources for two growing seasons, but in the third season the seedlings from ultramafic sources continued fair growth while others did not. To look for a similar delay of adaptive expression in ponderosa pine, I have outplanted seedlings of all families from my El Dorado stands on the serpentinite and marine soils supporting the seed parent and will evaluate their growth when the plantations are older.

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represents the research branch of the Forest Service in California and Hawaii.

Jenkinson, James L.

1977. **Edaphic interactions in first-year growth of California ponderosa pine.** USDA Forest Serv. Res. Pap. PSW-127, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

To investigate local adaptation to soil fertility, seeds were collected from trees in natural stands selected on one fertile and one nearby ultramafic soil in four geographic areas in the northern Sierra Nevada. Germinants from all seed parents in an area were planted in soils dug from the A horizon of both parent stands. Seedling growth on the fertile and ultramafic soils suggested no specific adaptation of parent stands to native soil. For every stand, the growth of seedlings from individual trees varied widely on both soils. Differences among families were highly significant, and one-fourth of the families showed significant differential responses to soil type.

Oxford: 174.7 *Pinus ponderosa*: 181.34:181.525:165.52.

Retrieval Terms: *Pinus ponderosa*; genetic variation; germination; plant-soil relations; seedling growth.

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Classification of Ponderosa Pine Stands under Stocking Control in California



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Site Classification of Ponderosa Pine Stands under Stocking Control in California

Robert F. Powers

William W. Oliver

CONTENTS

	<i>Page</i>
Introduction	1
Stand Characteristics	1
Methods	3
Field Procedure	3
Analysis of Data	4
Site Index in Younger Stands	6
Discussion	7
Height Growth Patterns	7
Soil and Stand Effects on Height Growth	8
Height Growth Patterns Compared with Standard Curves ..	8
Applying Results in Field Practice	8
Literature Cited	9

IN BRIEF...

Powers, Robert F., and William W. Oliver

1978. **Site classification of ponderosa pine stands under stocking control in California.** Res. Paper PSW-128, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Oxford: (794): 174.7 *Pinus ponderosa* — 114.7 [541 + 542]. *Retrieval Terms*: stocking density; soil productivity; *Pinus ponderosa*; site class assessment.

Several systems exist for determining site index in dense, unmanaged California stands of ponderosa pine. Each system involves height growth curves based on single measurements of tree height and age on temporary sample plots. Generally, such curves are anamorphic and fall short in reflecting the actual growth patterns of dominant trees grown under moderate stocking densities. This paper describes a new site classification system for California stands of ponderosa pine under stocking control. Additionally, a system for estimating site index in very young stands is described.

Stem analysis techniques were used in reconstructing periodic height and age for 135 dominant ponderosa pine in stands covering five physiographic provinces in northern California. These data formed the basis for polymorphic patterns of height growth to 80 years of age.

Tree growth on average and poorer sites was disproportionally less than on better sites during the first 15 years of stand development. Growth rates were proportional on all sites between stand ages of 20 and 60 years, but dropped rapidly on poor sites beyond 60 years of age. Contrary to trends described by most existing site index curves, rapid rates of height growth are possible

to age 80, providing stocking densities are moderate and soils fairly deep.

Conventional systems for estimating site index are inaccurate when applied to very young stands. There are two reasons for this. First, young stands seldom are sampled extensively in collecting base data for conventional site index curves. Second, young trees on stoney soils often grow well during their early development, but their growth rates drop rapidly as competition mounts for limited site resources.

We tackled the problem of estimating site index in very young stands by stratifying dominant trees by types of soil parent material and correlating the length of the first four branch internodes above breast height (height intercept) with height at age 50. On most soil types, site index could be predicted as a linear function of height intercept. But on skeletal schists, trends were significantly different. There, site index was less than that indicated by early growth rates.

Both systems for estimating site index are described in detail, and guides are given for applying them in practice. Yield tables for plantations of ponderosa pine based on the first system will be issued separately.

Site index, the height attained by a stand's dominant or dominant and codominant trees at an arbitrary index age, has been the basic measure of site productivity in the United States for over half a century. In California, several site index curves are used for estimating productive potential of even-aged stands of ponderosa pine (*Pinus ponderosa* Laws.). All of these (Arvanitis and others 1964; Meyer 1938; Dunning and Reineke 1933) are based on single measurements of current heights and ages of trees on temporary sample plots in dense, natural, unmanaged stands. As Lynch (1958) and Oliver (1967) have shown, height growth—and site index—are depressed at high stocking densities in ponderosa pine. Existing site index systems do not describe adequately the growth patterns of pine that will be managed under stocking control in California.

Ponderosa pine is an important part of California's forest resource. Here, nearly 4 million acres (1.6 million ha) are classed as commercial pine type (Forest Survey Staff 1954). An additional 8 million acres (3.2 million ha) support commercial mixed conifers in which ponderosa pine is prominent. Since 1960, over 130,000 acres (53,000 ha) of

National Forest land alone have been planted to ponderosa pine following logging, wildfire, or type conversion in California.¹ Site index will play a key role in future management decisions affecting these stands as silviculture is intensified.

Stands developing under uncrowded conditions show height growth trends differing significantly from those depicted by standard curves (Powers 1972). As part of a larger growth and yield study serving timber management needs in California,² we developed height growth curves for even-aged stands of ponderosa pine under moderate stocking density and managed for rotations of 80 years or less. These curves can be used to predict stand development and to assess site index for young-growth stands of ponderosa pine west of the Sierra Nevada crest and in the Warner Mountains of California.

This paper describes a system for estimating site index in stands where dominants have reached heights of at least 20 feet (6 m), and explains the method of its derivation. A second system, suitable for very young stands and allowing stratification by soil parent material class, is also described.

STAND CHARACTERISTICS

Data used to derive the site index system came from well-stocked, even-aged, pure or nearly pure ponderosa pine stands free of any past suppression. Stands in five physiographic provinces in California north of latitude 37° were surveyed. We favored natural stands growing at stocking densities approaching those for optimal timber production—roughly two-thirds of normal basal area (Meyer 1938)—although young, unthinned plantations were also included. So that site index could be assessed accurately, only stands near 40

years of age and older were considered for study. Twenty-six plots were established in natural stands and unthinned plantations in the northern Coast Range, Klamath Mountains, southern Cascade Mountains, Basin and Range Province

¹ Unpublished data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

² Oliver, William W., and Robert F. Powers. *Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California*. (Manuscript in preparation).

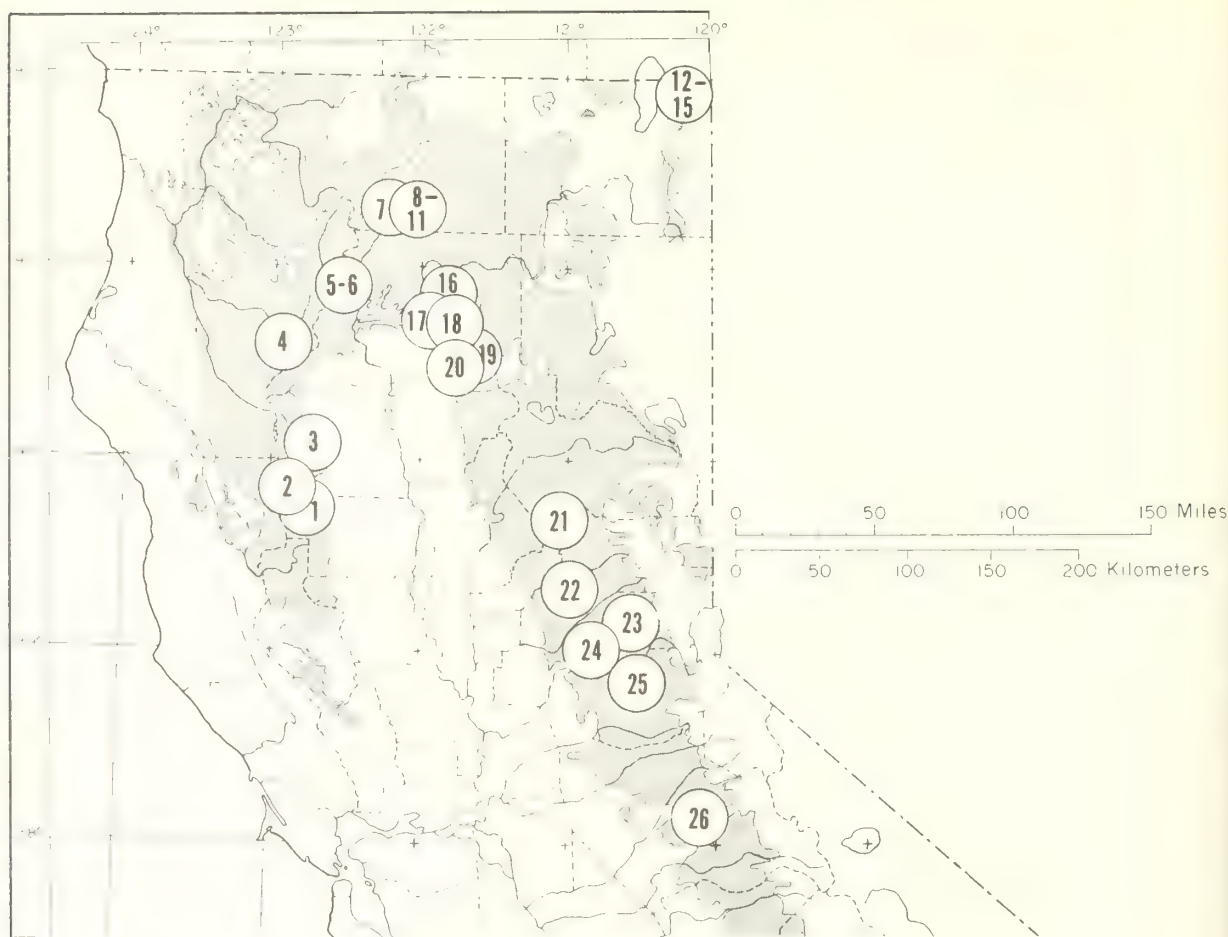


Figure 1—Study plots for ponderosa pine stem analyses were located throughout northern California. Characteristics of plots are described in *table 1*. Base map (adapted from Griffin and Critchfield 1972) shows distribution of ponderosa pine stands 2 miles wide or more (shaded area).

(Warner Mountains), and northern Sierra Nevada (*fig. 1*).

Soils supporting these stands were derived primarily from meta-sedimentary or basic igneous rocks (*table 1*). Despite the abundance of granitic rocks in the Sierra Nevada, none of our plots were located over this parent material. Timber stands associated with granitic soils in the northern Sierra Nevada are mainly the mixed-conifer and true fir forest types. And although many mixed-conifer sites have been planted to pine, no plantations on granitic soils were old enough for plot selection.

Stand ages ranged from 38 to 103 years (*table 1*). Point density estimates of basal area made on about half the plots yielded densities between 140 and 290 square feet per acre (32 to 67 sq m/ha).

Basal area stocking in natural stands generally was less than the normal given by Meyer (1938), whereas stocking in plantations tended to be greater than normal. We attribute the greater basal areas in plantations, compared with normal stands, to initial spacing control. Mean stand diameters for plantations tend to be greater than those found in dense natural stands of the same age and dominant height because of early advantages in growing space per tree. Unthinned plantations often reach greater basal areas but may have more stem taper than normal yield stands of the same age and dominant height, because there is less intertree competition.¹ Thus, “percent of normality” carries a different meaning in respect to basal area for plantations than it does for natural stands.

Table 1—Location and characteristics of plots and stands chosen for ponderosa pine stem analyses

Plot ¹	Physiographic province	Parent material	Stand age	Height at age 50 ²	Basal area as percent normal ³	Number of trees
			<i>Years</i>	<i>Feet</i>		
1. Alder Springs 1 (N)	N. Coast Range	Schist	70	82	71	5
2. Alder Springs 2 (N)	N. Coast Range	Schist	81	75	—	5
3. Pollard Corral (N)	N. Coast Range	Schist	66	71	—	5
4. Chanchelulla (N)	Klamath Mtns.	Gabbro alluvium	103	88	58	5
5. Shasta Lake 1 (P)	Klamath Mtns.	Metavolcanic	40	42e	—	8
6. Shasta Lake 2 (P)	Klamath Mtns.	Metavolcanic	40	54e	129	4
7. McCloud Flat (N)	Cascade Mtns.	Volcanic ash and alluvium	81	88	115	5
8. Show 1 (N)	Cascade Mtns.	Volcanic ash and alluvium	74	83	132	5
9. Show 2 (P)	Cascade Mtns.	Volcanic ash and alluvium	50	69	102	5
10. Show 3 (P)	Cascade Mtns.	Volcanic ash and alluvium	50	80	116	5
11. Henry's Find (P)	Cascade Mtns.	Volcanic ash and alluvium	46	76e	107	8
12. Sugar Hill 1 (P)	Basin and Range	Basalt	38	31e	92	5
13. Sugar Hill 2 (P)	Basin and Range	Basalt	38	40e	129	10
14. Sugar Hill 3 (P)	Basin and Range	Basalt	38	45e	113	5
15. Sugar Hill 4 (P)	Basin and Range	Basalt	38	54e	142	3
16. Round Mtn. (N)	Cascade Mtns.	Basalt	56	109	—	4
17. Buckhorn (N)	Cascade Mtns.	Andesite	64	98	93	5
18. Tamarack (N)	Cascade Mtns.	Basalt	88	95	—	5
19. Shafco (N)	Cascade Mtns.	Andesite	52	89	—	4
20. Midway (N)	Cascade Mtns.	Basalt	65	76	—	4
21. Forbestown (N)	Sierra Nevada	Metabasalt	97	92	70	5
22. Red Dog (N)	Sierra Nevada	Placer mine tailings	83	59	—	5
23. Elliot Ranch (N)	Sierra Nevada	Basalt	103	104	—	5
24. Foresthill (N)	Sierra Nevada	Schist	61	104	—	5
25. Sly Park (N)	Sierra Nevada	Basalt	51	117	—	5
26. Shanahan Flat (N)	Sierra Nevada	Schist	84	94	—	5

¹ N = natural stands; P = plantation.

² e indicates that height has been extrapolated.

³ existing basal area ÷ normal basal area (Meyer 1938) × 100 for stands of comparable age and dominant height.

METHODS

Field Procedure

Dominant trees in each candidate stand were examined for signs of past suppression or damage. Bole development and patterns of annual rings on increment cores taken at breast height were inspected, and any indication of restricted growth was cause for rejecting a tree from further study. An average of 15 dominant sample trees per acre (37/ha) were selected on plots ranging in size between 0.05 and 0.5 acres (0.02 to 0.2 ha). Plot areas varied with tree spacing and with the dimensions of stand units where site quality seemed homogeneous.

Total age was chosen as our time variable because it is directly applicable to management of plantations, where ponderosa pine silviculture will be practiced most intensively in the future. Unlike well-managed plantation trees, those in natural stands often suffer strong competition from other vegetation during early development. Consequently, early growth rates in natural stands often fail to reflect true site potential. There, breast-height age provides a more useful variable, but an adjustment factor must be used to obtain an estimate of total age that would reflect conditions of minimal competition. For our natural stands, total age was estimated from ring

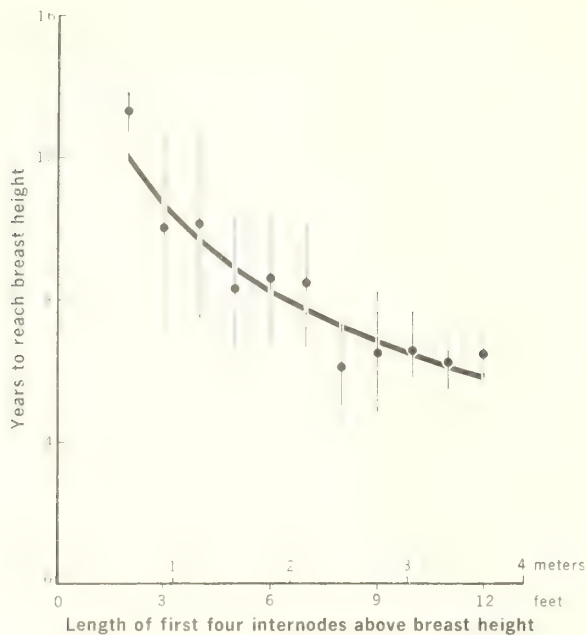


Figure 2—Total age of dominant ponderosa pine can be estimated from breast height age and the length of the first four branch internodes above breast height. Means and standard deviations for years to reach breast height are shown by 1-foot internode classes.

counts at breast height, using an adjustment factor based on the total length of the first four branch internodes above breast height (fig. 2). This factor supersedes the one we reported previously (Oliver and Powers 1971). Planting date (rather than age from seed) was the base age for the plantations we sampled. By the time trees reach breast height, little size difference is apparent between naturally seeded and planted stock, providing that sites have been prepared properly and that genetic differences are few.

To determine mean height at 5-year age intervals, heights to the first five branch nodes above breast height, then to each fifth node, and to the top of each tree were measured. A sectional pole was used for measuring heights to 40 feet (12 m) and an engineer's transit used thereafter. In all, 135 dominant trees were measured.

Analysis of Data

Periodic heights of sample trees were averaged for each of the 26 plots. The resulting data (mean heights of dominant trees at 5-year age intervals) suggested a sigmoid growth trend (fig. 3). The

height attained at 50 years total age defined the site index for trees on each plot. Heights ranged from 31 to 117 feet (9.4 to 35.7 m). Height at age 50 was estimated from past growth trends for the seven plots younger than index age (table 1). We felt justified in extrapolating growth trends on these plots because they were the poorest sites we measured and patterns are unlikely to change much in 10 to 12 years.

As a preliminary approach to describing site index curves, we applied to the data simple regression techniques developed for stem analyses (Johnson and Worthington 1963, Dahms 1975). Separate linear regressions were calculated for the relation of plot site index to the heights shown by plot dominants at successive age intervals above and below index age.

Each of the 15 data sets describing the relation of dominant height to site index at 5-year intervals for stand ages 10 through 80 years were plotted and inspected. A linear relation between mean dominant height and site index was shown clearly for stand ages 20 through 65 years, suggesting that proportional curves of the same basic form should describe growth accurately in this range. But nonproportional patterns appeared both at younger and older ages, suggesting that medium

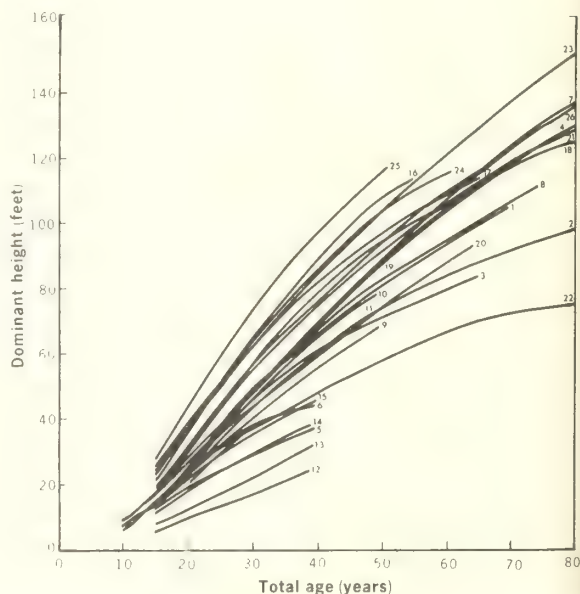
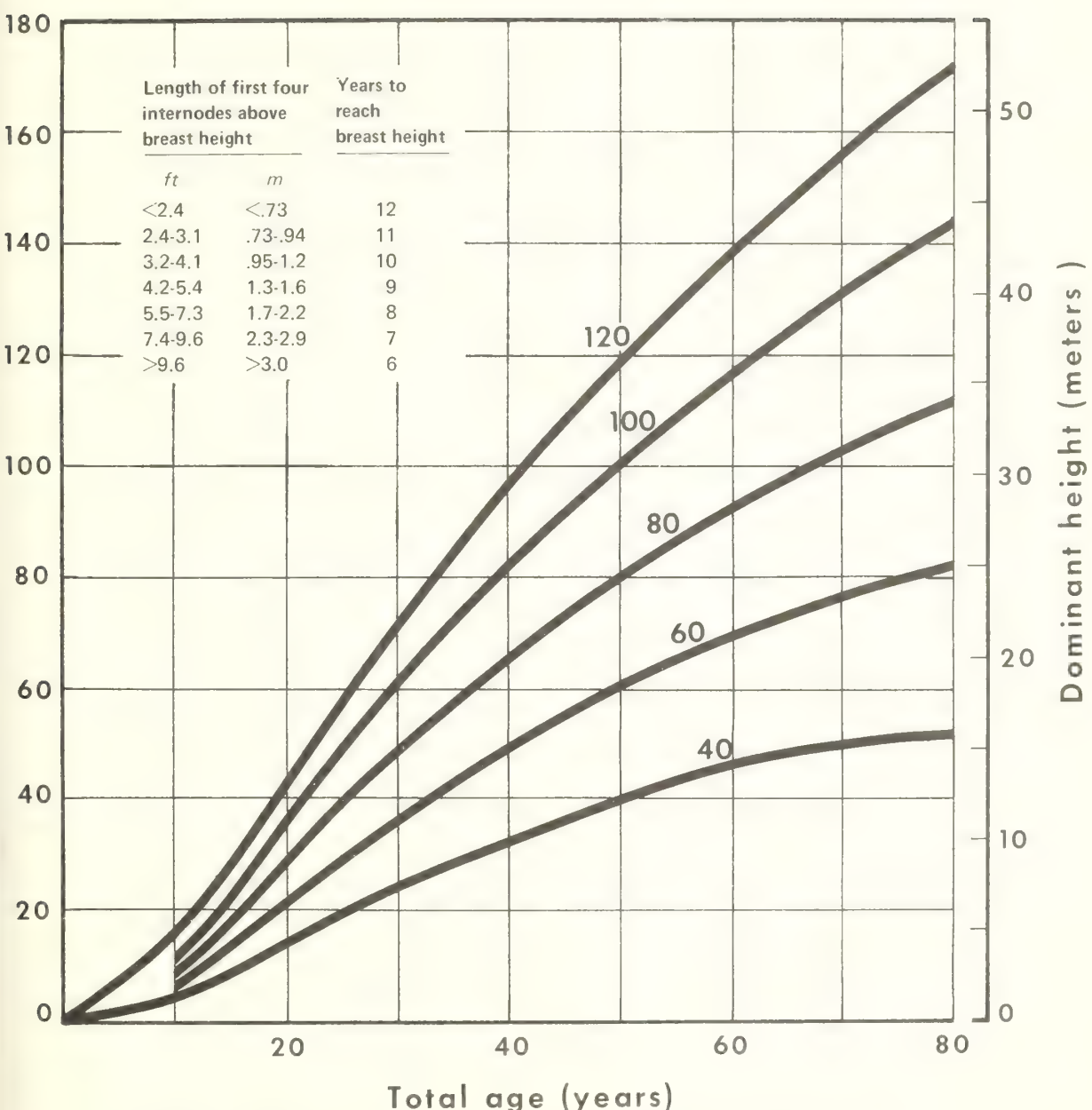


Figure 3—Mean patterns of height growth were plotted for dominant sample trees from plots described in table 1. Growth continued to be rapid at advanced ages, providing stocking density was not too high.



Site index curves for plantations and young natural stands of ponderosa pine

Figure 4—Site index curves for even-aged westside ponderosa pine were developed from stem analyses. Adjustment factors are shown for converting breast height age to total age.

Table 2—Periodic height of dominant ponderosa pine in relation to site index

Total age (yr)	Dominant tree height when site index is . . .				
	40	60	80	100	120
	Feet				
10	5	7	9	11	16
15	9	13	17	23	29
20	14	21	29	36	43
25	20	29	39	49	59
30	24	37	49	61	73
35	29	43	58	72	86
40	33	49	65	82	98
45	37	55	73	91	110
50	40	60	80	100	120
55	43	65	87	108	130
60	45	69	92	118	139
65	48	73	98	124	148
70	50	76	103	131	157
75	51	79	108	138	165
80	52	82	112	143	171

and poor sites produce trends differing slightly from those found on better sites. To compensate for this, growth trends were curved by hand for the ages of 10 to 20 and 60 to 80 years. Dominant heights for 20-foot (6-m) site index classes were taken both from freehand curves and regression equations at 5-year intervals between 10 and 80 years total age (table 2).

Data points in table 2 were plotted to develop the site index curves shown in figure 4. Patterns of height growth for trees younger than age 30 were compared with height data from 21 check plots in eight plantations too young to be used in the main study. Dominants on check plots ranged from 16 to 29 years in age and from 37 to 120 feet (11 to 37 m) in estimated site index. Check data generally supported the height growth trends we had described for trees below age 30. Some erratic patterns of height growth appeared; we attributed these to soil characteristics or brush competition. Few moderately stocked stands at advanced ages were available for checking the accuracy of our

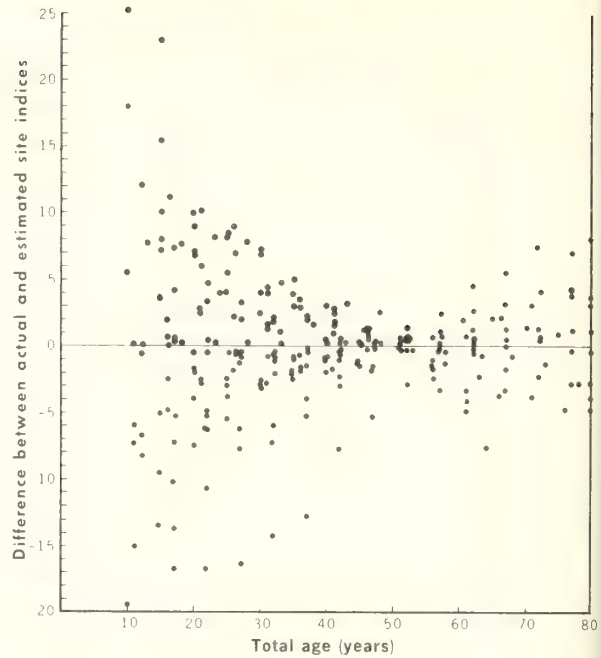


Figure 5—Differences between actual and estimated site indices decrease as index age is approached. From age 20 onward, errors in predicted site index generally are less than 10 feet at 50 years.

curves. Those that we were able to find did not conflict clearly or consistently with the trends shown in figure 4. Inspection of the deviations of estimated dominant heights from those actually attained (fig. 5) reveals no consistent bias.

We developed a five-parameter growth function for describing the curves in figure 4. The following equation estimates curve values of height within 2.3 feet (0.7 m) for site indices 40 through 120 and ages 10 through 80 years.

$$H = (1.88s - 7.178) (1 - e^{-0.025A}) (0.001S + 1.640)$$

where

S = site index in feet at base age 50 years

A = total age in years

R² = 0.999

SITE INDEX IN YOUNGER STANDS

Estimating site index in very young stands is a problem persisting in forestry. Oliver (1972) has shown that height intercept—the relation of the length of the first four internodes above breast height to site index—can be used in predicting site index either at base age 50 or 100 years. We reexamined Oliver's data by (1) calibrating height intercept against the new site index curves; and

(2) stratifying data by soil parent material classes (fig. 6). In all, over 200 dominant trees were examined over a site index range of 31 to 124. A general linear model described adequately the height-intercept—site-index relationship for all parent material classes except schist inceptisols (poorly developed metasedimentary soils lacking definite zones of accumulation). Analysis of

covariance helps confirm that trees growing on skeletal schists have lower site indices for a given height intercept than do trees on all other soils we studied. Predictive models describe these relationships:

For schist inceptisols (model I)

$$S = 17.57 + 6.75 \text{ HI}$$

$$r^2 = 0.79$$

$$s_{y,x} = 8.78$$

For soils other than schist inceptisols (model II)

$$S = 21.94 + 8.68 \text{ HI}$$

$$r^2 = 0.73$$

$$s_{y,x} = 11.08$$

where

S = site index (height in feet at 50 years)

HI = height intercept (length in feet of the first four internodes above breast height)

Multiply intercept coefficients by 0.305 if

HI is measured in meters.

r^2 = coefficient of determination

$s_{y,x}$ = standard deviation from regression

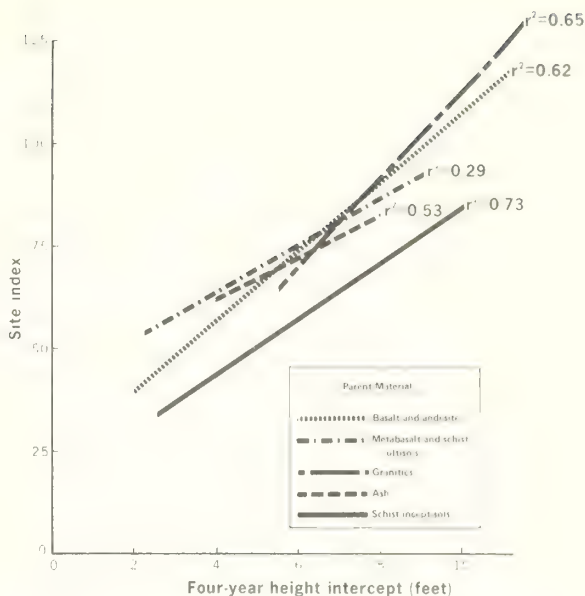


Figure 6—Site index can be predicted from the length of the first four branch internodes above breast height (height intercept). Trends are similar for trees growing on four classes of parent material, but are significantly different for those growing on schist inceptisols. Coefficients of determinations are shown for the trends in each parent material class.

DISCUSSION

Height Growth Patterns

The site index curves shown in *figure 3* are polymorphic—that is, their forms are dissimilar. Growth of trees on medium and poorer sites is disproportionately slower during the first 15 years of stand development than that on the best sites. Growth rates are proportional between 20 and 60 years. But by 65 years, growth slows disproportionately on poorer sites.

As shown by Curtis and others (1974) and Dahms (1975), differing systems of height-over-age curves can develop, depending on whether height or site index is the dependent variable in the basic regression equation. Strictly speaking, trends shown in *figure 4* (and most existing site index curves, for that matter) are more properly termed “height growth curves” because of the statistical treatment of the data. Although we recognize the distinction between site index and height growth curves, we believe that in this case the differences are unimportant. Differences between the two curve types are reduced if dominant trees, rather than dominants and codominants,

are the basis for site curve construction, and if the relative crown positions of sample trees remain fairly stable over time.

At ages near zero, neither height growth nor site index estimating curves give very reliable estimates of site index. True site index estimating curves generally do not pass through the origin, and often describe heights that are not biologically possible at early ages on the best and poorest sites (Curtis and others 1974). Conventional height-over-age curves do pass through the origin, but users may develop a false confidence in their precision for estimating site index in young stands. The scatter of points in *figure 5* indicates the confidence that can be placed on site index estimates using very young trees. For example, estimates of site index for sample stands from heights attained by trees aged 10 through 15 years showed an error of 10 or more site index units in 39 percent of the cases. Differences dropped rapidly with age, however, when height of older trees were taken as the base. Only 11 percent of the sample stands in the 21- through 25-year age

class differed by 10 or more site index units in their estimated and actual values.

Soil and Stand Effects on Height Growth

Estimates of site index in young stands may be biased because of certain soil characteristics controlling height development. For example, trees growing on ridge tops, on midslope benches, and on shallow or skeletal soils often gave lower site indices than indicated by early height growth. Generally, the reverse was true for trees growing on deep alluvial soils. Young plantations used as check stands showed similar growth patterns. Competitive vegetation is another factor in unusually slow early growth rates on poorer sites. For example, brush usually develops in young stands of widely spaced trees before crown closure. Our experience shows that for a given density of brush, the poorer the site the greater the competitive effect on tree growth. Until they reach dominant positions, trees on poorer sites have disproportionally greater competition from brush.

Trends indicated in *figure 3* show that rapid height growth can be sustained beyond 50 years on good sites, providing stand density remains moderate. Stands with rapidly decreasing rates of height growth tended to have basal area stand densities approaching normal stocking (Meyer 1938). Plot 8 in the Show 1 natural stand was an exception. There, height growth continued at a rapid pace although stand basal area was 131 percent of normal. This may be explained by the deep alluvial soil profile in that area, which seems free of horizons restricting root development.

Height Growth Patterns Compared with Standard Curves

Results gained with our system support conclusions of an earlier study (Powers 1972) that the systems of both Meyer (1938) and Arvanitis and others (1964) generate curves that underestimate later height growth in even-aged stands of ponderosa pine. Meyer's regional data came from unmanaged stands developing under strong competition. In fact, basal areas in the California stands he sampled exceeded normality by over 7 percent. Furthermore, less than 3 percent of his samples were from stands younger than 30 years. We do not believe the Meyer curves reflect accu-

rately the height growth patterns of young, moderately stocked, west-side ponderosa pine.

Adjusting the curves of Arvanitis and others (1964) for total age (*fig. 2*) and comparing them with *figure 4* showed comparable trends only for site index 40. We conclude that either their curves are distorted because of a sampling imbalance in age classes and site qualities, or that the higher stand densities in the unmanaged stands they sampled may have depressed height growth in older trees.

In our study, the Dunning and Reineke (1933) curves came closest of all published standards in describing height growth patterns for individual stands. Growth trends in the 1933 curves are far more linear, however, than growth patterns found in our study. We conclude that the Dunning and Reineke curves generally overestimate growth of trees younger than index age, particularly on medium and poorer sites.

Because suitable stands were not found on that parent material, the accuracy of the site index curves shown in *figure 4* for stands on granitic soils is unknown. Data from the height intercept study (*fig. 6*) suggests that early height-growth—site-index patterns for trees on granitics are indistinguishable from those on soils developed from different parent materials (other than schist). Still, trends on granitic soils should be compared against our curves when suitable stands are found.

Restricted rooting space probably is the primary reason trees on schist inceptisols give low site indices for given height intercepts (*fig. 6*). Schist inceptisols generally are skeletal—that is, at least 35 percent of the soil volume is composed of rock. The limited rooting space restricts growth severely as stands develop and stand densities increase. Stands growing on nonskeletal schists probably will develop according to model II, the general height intercept equation.

Applying Results in Field Practice

By the time dominant trees have reached heights of 20 to 30 feet (6 to 9 m) most seem to express site potential accurately (*figs. 3, 4*). To use the site classification system in *figure 4*, select an average of 15 dominant trees per acre (37/ha) from stand units that seem homogeneous, physically. Sample trees must show no sign of past suppression or injury above breast height. For natural stands, estimate total age of each tree by

adjusting breast height age using *figure 2* and the length of the first four internodes above breast height. Be alert for annual ring patterns showing abrupt changes between periods of slow and rapid growth. These indicate past suppression and release. For plantations, determine the total number of growing seasons from planting. Measure total height of each tree to the nearest foot (0.3 m). Finally, figure site index independently for each tree, using *figure 4*, and average these values to establish one site index for the stand unit.

For dominant trees that are less than 20 feet (6 m) tall, but have reached a breast-height age of at least 4 years, we recommend the height intercept method. Depending on the precision desired, select the appropriate number of the tallest trees per acre, as follows:

*Number of sample trees per acre (ha)
to estimate site index within...*

	± 20 ft	± 10 ft	± 5 ft
Soil parent material:			
Schist inceptisols	16 (40)	24 (60)	60 (150)
Other soils	16 (40)	28 (70)	88 (220)

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Avoid trees showing any top damage and stand units showing obvious site changes. For each tree, measure the length of the first four internodes above breast height and estimate site index using regression model I or II, depending on soil type. Then average site indices for all sample trees to obtain a single estimate of site index for the stand unit.

Although no single set of idealized curves can account fully for the variety of growth patterns found in nature, we believe the system described in this paper reflects the patterns found on most sites under moderate stocking control. We recommend that the classification system described in *table 2* and *figure 4* be adopted as the standard site index reference for managed stands of ponderosa pine west of the Sierra Nevada crest and in the Warner Mountains of California. Yield tables based on this site index system have been developed for plantations of ponderosa pine and will be published separately.



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Powers, Robert F., and William W. Oliver

1978. **Site classification of ponderosa pine stands under stocking control in California.** Res. Paper PSW-128, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Existing systems for estimating site index of ponderosa pine (*Pinus ponderosa* Laws.) do not apply well to California stands where stocking is controlled. A more suitable system has been developed using trends in natural height growth, derived from stem analyses of dominant trees in California. This site index system produces polymorphic patterns of height development to 80 years of age. Using a second system, site index can be predicted in stands where dominants have reached a breast-height age of at least 4 years but have not attained a height of 20 feet. Accuracy of estimates by this method can be strongly influenced by soil type. Accordingly, a separate equation is presented for stands on soils formed from skeletal schists. Yield tables based on the first system will be issued separately.

Oxford: (794): 174.7 *Pinus ponderosa* — 114.7 [541 + 542].

Retrieval Terms: stocking density; soil productivity; *Pinus ponderosa*; site class assessment.

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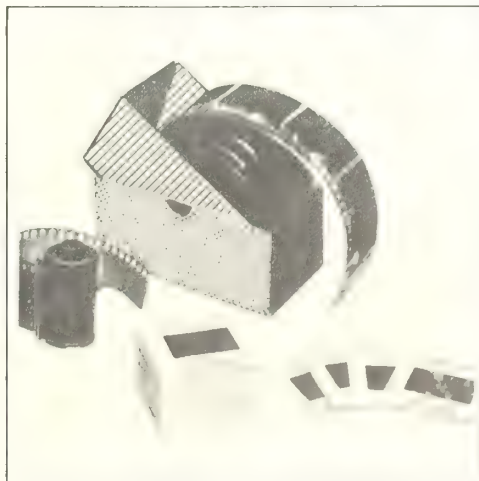
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PACIFIC SOUTHWEST Forest and Range Experiment Station

TEAM TEACHING FIRE PREVENTION PROGRAM: evaluation of an education technique

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TEAM TEACHING FIRE PREVENTION PROGRAM: evaluation of an education technique

Frank L. Ryan

Frank H. Gladen

William S. Folkman

CONTENTS

	<i>Page</i>
Introduction	1
Team Teaching Fire Prevention Program	1
Results	2
Public School Personnel Questionnaire	2
Ranger Unit Personnel Questionnaire	2
Evaluation of Effects on Students	3
Discussion	5
Further Evaluation Needs	6

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Oxford: 432 (794): 945.32.

Retrieval Terms: Fire prevention; education; children; program evaluation; California Division of Forestry.

Team Teaching is an important part of a coordinated program developed by the California Department of Forestry to meet the challenge of children-caused forest fires. Teams of from four to eight members conduct the program in individual classrooms. Each session is made up of three segments of about 10 minutes in length: (1) small group work; (2) slide presentation; (3) visit by Smokey Bear. The program has been in operation over much of the State for several years, and although informal feedback continued favorable, the Department felt the need for a more objective appraisal of its effectiveness.

In 1974, a State-wide survey was made involving school teachers and principals who had experienced the program in their classrooms, and Department personnel who had conducted the program. The response to the survey was quite uniformly favorable to the program. The intimate, small group discussion

method, which is central to the program, was strongly praised, as was the competence of the team members making the presentations.

This endorsement by those familiar with the program was encouraging, but the Department felt the need for an assessment that more directly examined the effect of the program on the students, themselves. In 1976, a study was conducted in San Bernardino County, California, in which children were tested before and after exposure to the program, and their responses compared with those from children who had not received the program. Students exposed to the program scored higher in tests of their understanding of fire prevention principles than did those who had not been exposed. Grade level and socio-economic status affected test performance. No differences, however, were observed in terms of attitude scores.

The decades following World War II were marked by rapid and drastic changes in the numbers, distribution, and living patterns of people residing in California. One aspect of these changes of particular concern to the California Department of Forestry was the significant, and growing, proportion of wildfires attributed to children. The Department's concern extended beyond the immediate problem of children-caused fires to what it portended for the future when this generation of children became careless adults.

In an effort to meet the challenge of this problem, the California Department of Forestry has developed a Five-Point Conservation and Fire Prevention Education Program for children in the early elementary grade levels. Included are classroom and individualized teaching materials, a series of short films, and a teacher training course. One important part of this Five-Point Program is its Team Teaching effort. Since 1967, the Department has introduced thousands of children in grades kindergarten through second to various themes of fire prevention through this program. The last several years have seen a drop in the proportion of "children-with-matches" fires reported in the State's fire statistics after about 20 years of increases.

The Team Teaching Fire Prevention Program is a labor-intensive, and therefore expensive, activity.

TEAM TEACHING FIRE PREVENTION PROGRAM

The original concept for the Team Teaching Program was developed by Richard K. Goings, then head of the Project Butte Fire Prevention Education Program, in cooperation with Dr. James F. Lindsey, who was principal of the laboratory school at California State University, Chico. Their work was part of an intensive fire prevention experiment in Butte County, California.²

In contrast to the traditional lecture method or the showing of a film to an auditorium full of children, the Team Teaching Program is conducted in three segments within individual classrooms:

1. Small group work (four to seven pupils in a group).
2. Slide or film presentation.
3. Visits by Smokey Bear, and reinforcement of principles learned.

Each segment lasts 10 minutes or less. The instruc-

tor is expected to stop before the collective attention span has lapsed.

Consequently, although the informal feedback was highly complimentary, the Department of Forestry was interested in having the program evaluated. In 1974, a survey was made of teachers and school principals who had experienced the program in their classrooms and of Department personnel who had been involved in actually conducting the program. The purpose of the survey was to determine their opinions of the effectiveness of the program.

Then in 1976, a study was conducted with students who had been exposed to the program to determine if it was effective, both in terms of students' understanding of fire prevention practices and in their attitudes toward various fire-related phenomena.

The two studies were made as part of an ongoing program of research on the problem of man-caused forest fires. The research is supported jointly by the Pacific Southwest Forest and Range Experiment Station and by the California Department of Forestry.

This paper summarizes results of the two studies¹ designed to measure the effectiveness of the Team Teaching Fire Prevention Program in California by surveying program participants. Other aspects of the program that might be evaluated in future studies are also summarized.

tor is expected to stop before the collective attention span has lapsed.

The fire prevention teaching team is composed of about five to eight trained fire specialists from the local Ranger Unit of the California Department of Forestry. One member serves as team leader. After a brief introduction, the team arbitrarily divides the class into small groups. Members of each group, in close eye-to-eye contact with a team member, discuss their responses to "Smokey's rules" for fire prevention and fire safety:

1. Do not play with matches.
2. If you find matches at home give them to a teacher or another adult.
3. If you find matches on the way to school, give them to the bus driver, teacher, principal, or another adult.
4. If you see someone else playing with matches, take the matches away and give them to an adult, if the

² Folkman, William S. 1973. *Fire prevention in Butte County . . . evaluation of an experimental program*. USDA Forest Serv. Res. Paper PSW-98, 23 p., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

¹ *The evaluation of 'Team Teaching' program of the California Division of Forestry, 1968-1974*, by Frank H. Gladen, and *Effectiveness of the Team Teaching Fire Prevention Program*, by Frank L. Ryan. (Unpublished reports on file at the Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.)

person is younger than you, or tell an adult.

5. If you see a fire burning out of control, don't try to put it out yourself, tell an adult.

These five rules serve as the instructional core that repetitively surfaces during each segment of the program. Following the small-group discussion, all students in the classroom are gathered together for a slide presentation conducted by the team leader. The slides depict forest wildlife, fire hazardous situations, and other forest fire-related subjects. The culminating experience is a visit by Smokey Bear (played by a team

member). Smokey reviews with the children the rules of fire they have learned.

The program was started with 11 kindergarten classes in the Oroville, Butte County area. It has since been extended to most of California, and agencies in other parts of the country have adopted the program. The original team was used as a cadre in training other teams. Later this training became a part of the Department of Forestry's Fire Academy curriculum at Ione, California. A training film has been developed to aid in the training of teams of teachers.³

RESULTS

Public School Personnel Questionnaire

Two hundred forty-three questionnaires were mailed to principals and teachers who participated in the program. A 65 percent return of useable responses was obtained.

Approximately 95 percent of the respondents considered the teaching approach used in the program to be a highly satisfactory method of presenting the fire prevention message. Because the team teachers are only in a classroom for a short period of time, the regular classroom teacher is encouraged to reinforce the program with some type of follow-up activity. The questionnaire response indicated that 63 percent of the teachers frequently did so. The others were reported to sometimes reinforce the instruction. Thirty-five percent of the teachers said that the messages of the program had become a part of their curriculum through an increased general awareness.

When asked to rate the Team Teaching Program in comparison with other outside programs presented in their school in the previous three years, 85 percent of the respondents rated it better than most, 10 percent considered it about average; and the others did not answer.

The Department of Forestry team members were unanimously reported to be reliable in their arrangements with the school as to date, time, and place. The Department prefers to give the program in the spring because of its nearness to the fire season. The schools likewise felt that this was the logical time for the program.

The program has usually been presented to kindergarten and first grade students. Eighty-nine percent of the school respondents felt that it would be appropriate to extend it to grades two and three.

Ranger Unit Personnel Questionnaire

The Butte County Ranger Unit began using the program in 1967. In 1970 another Ranger Unit became involved; in 1971, two more; in 1972, six; and in 1973 four additional Units began using the program.

Questionnaires were sent to all Ranger Units throughout California, except for those where it was definitely known that they had not participated in the program. Of the 18 Ranger Units contacted, five reported that they were not currently participating in the program although one had done so previously.

The Team Teaching Program was reported to be in operation usually November through May. The bulk of its activity was concentrated in March, April, and May.

Numbers of people making up the teams ranged from four to eight, with seven being the typical number.

The amount of effort expended and the coverage obtained by the units engaged in the program were

<i>Years:</i>	<i>Man-hours expended</i>	<i>Schools visited</i>	<i>Children contacted</i>
1971	2,110	84	4,188
1972	4,382	231	23,899
1973	5,924	287	28,022

This represents an expenditure of approximately 0.2 man-hours per child instructed. Most respondents mentioned manpower limitations as the principal problem they experienced in conducting the program. The responses to the questionnaire reflected a high degree

³ Film is available for review from the California Department of Forestry, 1416 Ninth Street, Sacramento, California 95814.

of enthusiasm for the program and a feeling that it was very worthwhile. Fifty-seven percent of the units reported a decrease in the incidence of children-caused fires as a result of their team teaching activity. The other units reported that they had not yet detected any change. None reported any increase.

Only two respondents offered suggestions about how the benefits of the Team Teaching Program could be achieved at lower cost. One suggested making better transportation arrangements. Another proposed that summer fire fighters be hired early and used in teaching under supervision.

In summary, a poll of Team Teaching members and their clients showed a high level of satisfaction with the program. Although this result may represent an accurate assessment of the effectiveness of the program, it remained essentially a subjective impression, however widely shared. The ultimate test remains—what effect does exposure to the program have on the children? Regardless of how good everyone feels about the experience, the program fails to meet its objectives if the pupils do not learn fire-safe behavior. Consequently, it was deemed necessary to conduct a study to directly evaluate the effect of the program on students experiencing it.

Evaluation of Effects on Students

The main purpose of this study was to determine if the program was effective, both in terms of students understanding fire prevention practices and of their attitudes toward various fire-related phenomena. This focus was in contrast to the earlier study's concentration on the receptivity to the program by teachers and school administrators.

Key personnel from throughout California who were identified as policy makers, planners, or instructional leaders for the program were contacted to determine the current objectives of the program. It became clear that a continuing primary objective of the program's instruction was to have the students be able to recognize and recall the five rules of fire prevention. Other objectives were that the children develop a cautious respect for fire and matches and a positive attitude toward rangers.

On the basis of data collected concerning the specific objectives of the program, we developed and tested some measures of achievement and attitudes.⁴

⁴Detailed explanation of these measures is available upon request to the Wildfire Prevention Research Unit, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, California 94701.

San Bernardino County was selected as the site for the study. This decision was based on several factors, including the accessibility of the county to the evaluators from the University of California, Riverside; the diversity of the population; a history of an early entrance and active participation of the San Bernardino Ranger Unit in the program; and, very importantly, the willingness of the San Bernardino Ranger Unit staff to cooperate in such an evaluative undertaking.

With the assistance of county and district school officials, all schools in San Bernardino County that had not participated in the Team Teaching Fire Prevention Program since 1973 were classified as being low, middle, or high socio-economic status (SES), and either urban or rural. Using the resultant classifications and based on proportional data available for the State of California as to the stratification factors of SES level and geographic region (U.S. Department of Commerce 1976), we selected a random sample of schools for the study. All kindergarten through second grade classrooms within each school selected (with the exception of special classes, such as the trainable mentally retarded), were included in the study. Twelve schools with an enrollment of 2451 kindergarten, first-, and second-grade students were randomly selected for further evaluation.

Although all kindergarten, first- and second-grade students in those schools randomly selected were provided the procedures of the study, final statistical analysis was confined to those students in a final randomized selection. The number selected was based on the percentage distribution of California families among the SES levels, in both urban and rural areas. We concluded that the application of the stratified technique provided for an adequate simulation of the State of California—at least with respect to SES and geographical area.

Classes within each of the study schools were randomly designated as either experimental or control classes. On any particular day of the team teaching, experimental classes first received instruction, followed by administration of the attitudinal and achievement tests. Control classes were first tested and then received the fire prevention instruction. For the purposes of the evaluation, it was not necessary for the control classes to receive the instruction, but it served to preserve student morale. Furthermore, it served to conceal the experimental and control class designations from all but the members of the evaluation staff.

Differences between experimental and control scores on the achievement tests were marked, indicating that students did attain specific understandings as a

Table 1—Achievement test means and standard deviations for experimental and control groups, by grade and socio-economic level

Socio-economic status level and test ¹	Kindergarten				First grade				Second grade			
	Experimental		Control		Experimental		Control		Experimental		Control	
Low	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
1	4.33	1.23	2.30	1.99	6.73	2.31	3.49	1.97	7.48	1.87	4.72	2.34
2	5.41	1.90	1.51	1.27	6.19	2.39	2.93	2.28	7.96	2.24	3.37	1.99
3	9.40	2.32	4.98	2.72	10.28	2.91	5.78	3.03	13.01	3.41	7.01	3.56
Medium												
1	5.01	2.17	1.97	1.20	6.62	2.26	2.91	1.66	8.61	2.29	2.98	2.12
2	4.11	1.87	2.36	2.20	6.91	2.11	3.23	2.24	9.14	2.33	4.27	2.13
3	10.01	2.47	5.07	2.84	10.23	3.27	6.30	3.20	12.95	2.99	7.73	3.13
High												
1	6.82	1.24	3.27	2.21	8.15	2.13	4.12	2.34	9.35	2.42	5.43	2.00
2	6.92	1.90	3.53	1.88	7.78	1.99	4.75	2.42	8.90	2.33	5.20	2.26
3	11.65	2.06	6.99	3.02	14.21	3.81	7.29	3.14	15.90	3.08	8.39	3.11

¹1 = Measure of recall of fire rules.

2 = Measure of applied knowledge.

3 = Composite factor.

result of their participation in the program (table 1). The achievement tests measure three different elements: (1) recall of the five rules of fire prevention emphasized in Team Teaching; (2) the transfer or application of knowledge learned; and, (3) a measure derived by factor analysis containing test items from the first two elements and, therefore, labeled the Composite Factor. (Significance of differences noted were determined by multi- and uni-variate analysis of variance.)

Analysis of the achievement test data gave these results:

1. The experimental group performed better than the control group on each of the three achievement measures.

2. The performance was significantly better whether measured by an over-all or average of the three dependent variable scores or by each separate dependent variable score.

3. The second graders performed better than the first-graders or kindergartners.

4. First-grade students performed better than those in kindergartners.

5. Students of high socio-economic status performed better than those of middle or low status.

6. Students in the middle and low socio-economic status did not differ in scores.

7. No interactive effects between the variables were found.

Although the response scales for the attitude tests had been written for three constructs (fires, matches, rangers), factor analysis show student responses clustering about just two factors, with rangers dominating

one factor and matches the other. The construct, fires, was a subordinate element in each factor.

Scores for all grade levels for both experimental and control groups show little variation (table 2). All tend to cluster in the lower quartile for the test in which possible scores range from 10 to 30. Analysis of these data showed:

1. No differences on any variable were observed in terms of attitude scores.

2. No interactive effects were apparent.

3. No differences on each separate dependent variable due to attitude were evident.

In one of the schools included in the study, the program was implemented by using a woman volunteer team and a regular fire personnel team. The classes were randomly assigned to the two teams. In terms of student achievement, both women volunteers and regular personnel were effective, the regular personnel more so than the volunteers. There was no evidence that either team produced any attitude change on the part of students (table 3).

In summary, the evaluation of the effects of the program on students suggests that students acquired understandings as measured by recall of the five rules and as measured by the applied-knowledge test. Such increased understanding occurred at each of the grade levels studied, with second graders outperforming first graders and kindergartners, and first graders achieving more than kindergartners. Students in each of the three socio-economic status levels also showed improvement, but with those in the high SES outperforming students from middle and low SES. Both women volunteers and regular fire personnel proved effective

instructors, but regular personnel produced more student achievement than did the volunteers. There was

no evidence that student attitudes changed as a result of the program's instruction.

Table 2—Attitudinal means and standard deviations for experimental and control groups, by grade and socio-economic status (SES) level

Socio-economic status level and score ¹	Kindergarten				First grade				Second grade			
	Experimental		Control		Experimental		Control		Experimental		Control	
Low	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
1	13.28	2.97	14.34	3.31	14.15	3.06	12.99	2.96	13.80	4.02	14.28	4.71
2	14.01	3.52	14.22	2.72	13.82	3.71	13.66	3.42	14.29	5.71	14.23	3.56
Medium												
1	14.20	3.26	12.99	3.91	13.63	2.41	14.12	3.36	13.71	4.37	13.55	4.33
2	13.72	2.90	13.12	3.76	13.39	3.69	13.72	3.29	13.77	6.05	14.09	3.12
High												
1	14.31	2.91	13.43	2.75	13.04	3.72	14.01	4.75	14.61	4.13	14.37	3.17
2	13.92	3.55	14.61	3.83	13.95	3.21	13.39	3.20	14.27	5.73	13.82	3.92

¹1 = FIRES-matches factor

2 = RANGERS-matches factor

Table 3—Achievement test means and standard deviations according to grade level, by type of instructors

Instructors and tests ¹	Kindergarten				First grade				Second grade			
	Experimental		Control		Experimental		Control		Experimental		Control	
Regular fire personnel:	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>
1	5.35	2.20	2.03	1.51	7.21	2.20	3.95	2.12	8.96	1.82	5.00	1.72
2	4.72	1.85	2.20	2.20	7.06	2.18	3.26	1.68	9.09	2.14	6.01	2.91
3	9.47	1.64	6.33	2.15	11.72	2.43	7.14	1.75	13.17	2.35	9.42	1.70
Women volunteers:												
1	3.21	2.43	2.03	1.51	5.26	1.49	3.95	2.12	7.79	1.68	5.00	1.72
2	3.12	1.85	2.20	2.20	4.39	1.62	3.26	1.68	8.40	1.99	6.01	2.91
3	7.89	1.97	6.33	2.15	9.21	1.71	7.14	1.75	11.15	1.74	9.42	1.70

¹1 = Measure of recall of fire rules

2 = Measure of applied knowledge

3 = Composite factor

DISCUSSION

The feedback from teachers and school administrators and the results of the student evaluation all testify to the effectiveness of the Team Teaching program. Students are certainly learning from the program. It is particularly impressive that such learning occurs within a brief 25- to 30-minute instructional period.

Some of the strengths of the program may be gleaned from the reports of teachers who had observed it in operation in their classrooms. Teachers frequently, and approvingly, mentioned how the small-group discussion method encouraged each child to

participate. They noted the ability of the rangers to deal with the children on a friendly, personal basis. The fast moving pace of the program, efficient, professional organization, and the enthusiastic involvement of the rangers were also approved.

In the main, negative criticism centered around what were apparently deviations from the established format of the program. One team requested that the children be brought to them in a vacant room rather than presenting the program in the classroom as previously arranged. From another teacher's comments it appears

that a team discontinued the small-group discussion that is central to the program and that the teacher had found so effective the previous year. In another instance, an attempt to conduct the program with too few trained members resulted in reduced individual interaction in the consequent larger groups of children. Several teachers suggested that a bilingual team member would be effective in working in schools with a number of Spanish-speaking students. There were some criticisms of the slide portion of the program—a need for a better selection of slides and a slower tempo in narration were mentioned.

Teachers were sensitive to the way some teams left them without a role in the program (some teachers apparently were even asked to leave the room during the presentation). Limiting the teachers' observation of the students' experiences left them at a disadvantage in implementing valid followups to the program.

The study of the children's responses to the program pointed out several other possibilities for amending, buttressing, or embellishing it.

Consideration should be given to the expansion of the program objectives to include not only the immediate recallable (i.e., the five rules) but also more involved forms of understanding. Thus in the slide presentation, for example, with some modification in the questions posed, students could be provided a greater opportunity to interpret and apply what they

have learned to a broader range of fire-related activities and phenomena. No additional time would be required for implementing this suggestion.

Although the study showed that regular fire personnel were more effective than volunteers in increasing student understanding, this difference should not be considered immutable. We found nothing that would suggest that volunteers could not become equally effective teachers within the program, given comparable in-service training.

By the way they conducted the discussion or phrased the questions, some instructors would provide increased opportunities for more student involvement. Others, by asking a preponderance of questions requiring a mere "yes" or "no" answer or by intonation, left little doubt as to the answer they expected. As a result, some students may have felt that they contributed little to the discussion.

Although attitude toward the program appeared to be mostly positive and the students seemed genuinely interested in seeing and listening to rangers, no attitudinal changes were detected in terms of the two constructs (Rangers—fire, Matches—fire) measured. Whether or not these results are to be interpreted as acceptable is best left to the officials of the program. As a minimal response, those with policy responsibilities might delineate more specifically the desired attitudinal objectives for the program.

FURTHER EVALUATION NEEDS

In the studies summarized here, assessments of the program were obtained from school teachers and administrators and from agency personnel involved in the program. In addition, comparisons were made between experimental and control groups and between women volunteers and regular fire personnel teachers. No study provides answers to all questions. One of the more significant functions of any research study is in posing additional significant questions. Further evaluative studies of the Team Teaching program could include answers to such questions as:

1. What are the effects, if any, of repeated student exposure to the program?
2. What are the effects of time on retention and attitude change (which often follows cognitive change) as revealed by followup testing?
3. In what ways, if any, does the incidence of fire starting change after students within an area have been

exposed to the program?

4. In what way, if any, is the program effective in terms of such behavior as getting students to turn matches in to the proper people?

5. What are ways to decrease the dependence on regular fire personnel participation without decreasing the program's effectiveness? (e.g., increase the use of trained volunteers? greater involvement of the regular classroom teachers? increase the size of the "small" groups?)

6. What are other instructional options, both in terms of materials and consequences of activities, that are as effective, or even more effective, than the present program?

As with any action program, periodic assessments should be made to assure that the integrity of the Team Teaching program is maintained and that its full potential be developed.

Ryan, Frank L., Frank H. Gladen, and William S. Folkman

1978. **Team Teaching Fire Prevention Program: evaluation of an education technique.** Res. Paper PSW-129.6 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

The California Department of Forestry's Team Teaching Fire Prevention Program consists of small-group discussions, slides or films, and a visit by Smokey Bear to school classrooms. In a survey, teachers and principals who had experienced the program responded favorably to it. The conduct by team members also received approval. The limited criticisms of the Program centered around apparent deviations from the established format. In a separate study, students exposed to the Program scored higher in tests of their understanding of fire prevention principles than did those who had not been exposed. Grade level and socio-economic status affected test performance. No differences, however, were observed in terms of attitude scores.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

Control of Douglas-fir Tussock Moth by Aerially Applied Dimilin (TH 6040)

John S. Hard

James D. Ward

Steven Illytzky



The Authors

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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife — if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Control of Douglas-fir Tussock Moth by Aerially Applied Dimilin (TH 6040)

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CONTENTS

Introduction	1
Materials and Methods	1
Results and Discussion	3
Literature Cited	4
Appendix	5

IN BRIEF...

Hard, John S., James D. Ward, and Steven Ilnytzky.

1978. **Control of Douglas-fir tussock moth by aerially applied Dimilin (TH 6040).** Res. Paper PSW-130, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Oxford: 145.7x18.77 *Orgyia pseudotsugata:* 453—414.12 Dimilin: (711)

Retrieval Terms: tussock moth, Douglas-fir, insecticides, performance tests, Pacific Northwest, British Columbia.

Tests were made in 1976 on epidemic Douglas-fir tussock moth populations in the North Thompson River Valley north of Kamloops, British Columbia, to determine the minimum effective amount of Dimilin required for tussock moth population control. Three dosages of Dimilin per gallon of water, 2.0 oz, 1.0 oz, and 0.5 oz, were aerially applied with fixed-wing aircraft at about 1 gallon per acre in a randomized block experiment. The nine treated plots and three check plots ranged from 50 to 81 acres in area and 2300 to 2900 feet in elevation. Larval populations were monitored 1 day before spray application and 7, 14, 21, 28, and 35 days after spray application to determine (a) the effect of treatment on larval mortality, and (b) the incidence of naturally occurring tussock moth virus infection in the experimental plots.

Mean numbers of surviving larvae per 1000 in² at 35 days postspray in the 2.0-oz, 1.0-oz, and 0.5-oz, and check plots were 1, 15, 22, and 60 larvae, respectively. Mean percent unadjusted mortalities at 35 days postspray were 99.7, 92.2, 89.7, and 61.1 percent. Numbers of surviving larvae per 1000 in² were significantly different at 35 days postspray between (a) the 2.0-oz treatment and (b) the 1.0-oz and the 0.5-oz treatments, and at 28 and 35 days postspray between (c) the three Dimilin treatments and (d) the untreated checks. Analysis of percent unadjusted mortalities showed significant differences between (a) the 2.0-oz treatment and (b) the 1.0-oz and 0.5-oz treatments at 14, 21, 28, and 35 days postspray.

Virus infection did not cause high larval mortality in the experimental areas until after the experiment was terminated. The tussock moth outbreak collapsed, however, during the late larval period; the collapse is attributed to a combination of virus, late larval and pupal parasitization, and unusually cool, wet weather in August.

Sample trees were heavily defoliated only in untreated and 0.5-oz treated plots. We recommend, however, that no less than 2.0 oz of Dimilin per acre be pilot-control tested for Douglas-fir tussock moth population control during the rising phase of a tussock moth outbreak.

When ingested by insects and other arthropods, Dimilin (1-(4-chlorophenyl)-3-(2,6-difluorobenzoyl)-urea), causes mortality by interfering with cuticle deposition during molt (Post and Vincent 1973). This highly water-insoluble chitin-formation inhibitor is an insect stomach poison; its toxicity increases inversely with suspended particle size (Mulder and Gijswijt 1973). It is rainfast,¹ and has a residual life on sprayed foliage in the field of at least 3 to 4 weeks (Granett and Dunbar 1975, Pree 1976) and up to 4 months (Skatulla 1975). Because of its mode of action, its toxicity to vertebrates is extremely low.

Dimilin has been tested and proven effective against a variety of forest insect pests (Skatulla 1975), and is considered to be quite safe environmentally. It caused molt inhibition of gypsy moth larval parasitoids when host larvae were fed Dimilin-treated leaves (Granett and Weseloh 1975); however, in a later study (Granett

and others 1976) percent *Apanteles* emergence differed significantly between treated and untreated gypsy moth hosts only when these were treated during the first and second larval stadia. It also adversely affected reproduction in a species of brine shrimp (Cunningham 1976).

An aerial application in 1975 of 4.0 oz a.i. (active ingredient)/gal/acre (280.1 g a.i./9.3 l/ha) reduced larval populations of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), 100 percent over 21 days, but was considered to be an overdose (Neissess and others 1976). This report describes the results of an aerial test in 1976 of three reduced Dimilin dosages applied to a declining tussock moth population to determine the minimum application rate effective for Douglas-fir tussock moth control. Procedures are described in detail so that the experiment can be reproduced on rising tussock moth populations, if desirable.

MATERIALS AND METHODS

Four rectangular plots were established in each of three areas in the North Thompson River Valley at elevations ranging from 2300 to 2900 ft (700 to 900 m) approximately 12 mi (20 km) north of Kamloops, British Columbia. A total of 300 nondefoliated, egg mass-bearing, open-grown Douglas-fir, [*Pseudotsuga menziesii* (Mirb.) Franco], 30 to 50 ft (9.1 to 15.2 m) tall were selected, 25 per plot, for tussock moth larval sampling.

A randomized block experimental design was used, with one replicate of each of four treatments in each block. Treatments were aerially applied Dimilin W-25 (25 percent wettable powder)² water suspensions of 2.0 oz a.i./gal (15.0 g a.i./l), 1.0 oz a.i./gal (7.5 g a.i./l), 0.5 oz a.i./gal (3.75 g a.i./l) and untreated checks. Treated plots were sprayed with about 1 gal (3.8 l) of formulation per acre (0.41 ha). The water-based formulations contained 10 percent ethylene glycol by volume to achieve finer spray atomization than an unadulterated water carrier provides. All for-

mulations contained 7.56 g/gal (2 g/l) of Rhodamine B Extra S (GAF) dye for spray deposit assessment.

Plot treatments in each block were randomly assigned but in block 1 the 0.5-oz and the 2.0-oz treatment assignments were reversed because of potential spray drift from the upper plot to the lower plot. We felt that if drift was to occur, drift of 0.5-oz formulation onto a 2.0-oz treated plot would have less chance than the reverse drift of obscuring treatment effects.

Plots were sprayed as soon as weather permitted after 100 percent of monitored egg masses on the plots hatched and all larvae were dispersed from the egg masses. When treated, most larvae were in the second instar. All treated plots within a block were sprayed on the same day, but each block was treated on a separate day — June 13, June 17, and June 18 — so that date of treatment was the blocking factor.

The order of application of each formulation was changed on each day of treatment to prevent bias that might be introduced by variation in meteorological conditions during the hours that spray was applied. This restriction of randomization had no apparent effect on results of significance tests because time of day when spray was applied proved unimportant. Temperature, relative humidity, wind speed, and direction of airflow were monitored and recorded in each block by a professional meteorologist during spray application (see Appendix, table 3).

Formulations were mixed the morning they were to

¹Robertson, J.L. 1976. *Bioassays to provide supporting data for the design and execution of field tests and screening new candidate materials*. (Report on file, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.)

²Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

be sprayed. They were applied in 100-ft (30 m) swaths from a Cessna Ag Truck flying 100 ft (30 m) above the trees, using a wind-driven pump and conventional spray boom with 22 evenly spaced flat fan tips (Spray Systems, Wheaton, Ill., T8010). Colored treetop banners were used to mark plot corners and midpoint of the end of each plot. The pilot was instructed to apply 13 evenly spaced spray swaths to each plot, parallel to the long plot axis. An aerial observer having radio contact with the spray pilot flew in a helicopter above the spray aircraft to insure that spray swaths were distributed evenly across each plot. Spray parameters (*see Appendix, table 4*) were recorded by an electronic device mounted in the spray aircraft. Plot areas were measured on the ground after all plots were treated.

One 4- by 4-in (10.2- by 10.2-cm) Kromekote card was placed in the open at ground level near each sample tree on treated plots to sample spray deposit. Kromekote cards were placed in untreated plots to detect spray drift from treated plots. A Quantimet Image Analyzer was used to determine spray droplet volume median diameter and mean number of droplets per square centimeter for each treated plot.

Larval populations were sampled at 1 day before spray, and 7, 14, 21, 28, and 35 days postspray. The last 35-day sample was taken on July 23 in block 3. Two midcrown branch samples were removed from each tree at each sample date. Branch length, width, and number of live tussock moth larvae were recorded for each sample. An additional subsample of two or four live larvae was collected from each tree at each sample date, and the larvae were reared singly in the laboratory on artificial media³ to determine incidence of virus infection during the experiment. Larvae that died in rearing were examined microscopically to determine cause of death.

Larval population data transformed to number of larvae per 1000 in² (6452 cm²) of foliage, and percent unadjusted mortality at each sample date, were treated as independent samples and were subjected to analyses of variance. Technically, however, the samples are a time series of nonindependent measurements because the same trees were sampled repeatedly. Appropriate orthogonal contrasts were computed at postspray sample dates to test significance of differences among treatments. Contrasts for percent mortalities were computed only for treated plots because percent mortality variances were unequal between treated and

untreated plots. Pooled variances of percent mortality in all treated plots were computed for all postspray sample dates, and the power of the experiment to detect significant differences in mortality was calculated (Pearson and Hartley 1951).

Percent unadjusted mortality of each treated plot and residual number of live larvae at 35 days postspray were both plotted against applied dosage rates [a.i. applied per acre = (spray flow in gal X oz a.i. per gal formulation) / plot area in acres] and linear models were computed.

Amount of crown completely defoliated on each sample tree was estimated and recorded in October 1976.

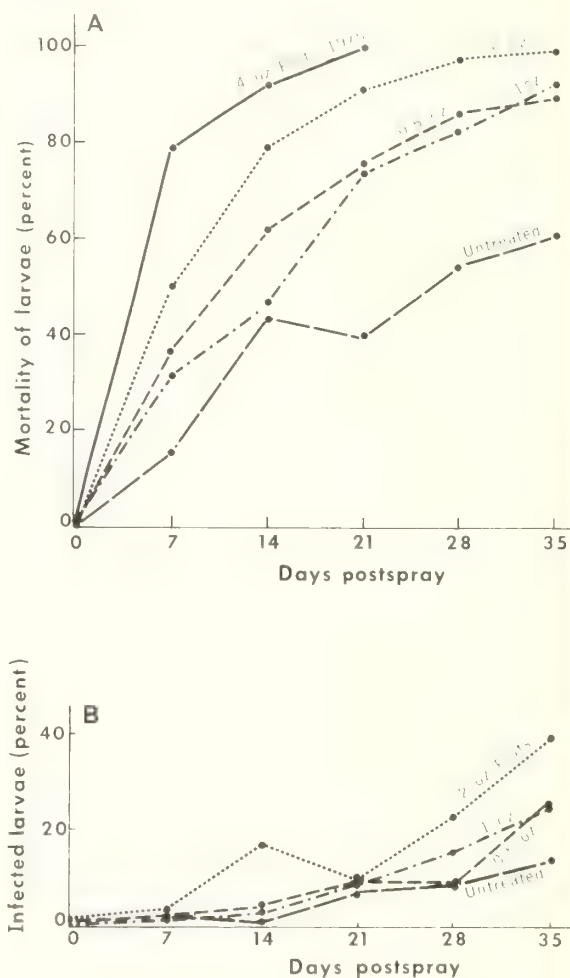


Figure 1—Larval populations of Douglas-fir tussock moth were sampled periodically in 1976 on plots aerially treated with Dimilin at several dosages (oz. a.i./gal). (A) Mean percent larval mortality increased more in treated plots than in untreated plots following treatment. Mortality found in 1975 by Neisess and others (1976) is graphed for comparison. (B) Mean percent virus infection of live larvae collected on the same sampling dates, and reared in the laboratory, increased during the experiment.

³Thompson, C.G. 1966. *Douglas-fir tussock moth virus test, Phase 3. Simulated field test to determine virus dosages and concentrations.* (Report on file, Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.)

RESULTS AND DISCUSSION

Spray deposit on all treated plots was adequate (*see Appendix, table 5*) and Kromekote cards set out in untreated plots revealed no spray drift from treated plots. As expected, however, an extremely small amount of 0.5-oz a.i./gal spray drifted onto the 2.0-oz a.i./gal treated plot on June 13 because of downslope air drainage.

The 2.0-oz treatment resulted in almost 100 percent tussock moth control at 35 days, and is comparable to control on the 4.0-oz plots at 21 days in 1975 (*fig. 1A*). Results of the experiment were not obscured by virus because virus infection (*fig. 1B*) did not cause high mortality in the plots until after the last population sample was taken.

Analysis sensed significant larval population differences at 28 and 35 days postspray between treated and untreated plots, but only at 35 days postspray between the 2.0-oz and lower dosage plots (*table 1*). Analysis of percent mortality, among treated plots only, appeared to sense significant differences between 2.0-oz and lower dosage plots at 14, 21, 28, and 35 days postspray (*table 1*). Estimates of experimental power, calculated from pooled variances of percent mortality, indicated that these apparently significant differences were truly detectable at these postspray periods (*see Appendix, table 6*). If the corresponding differences for the 7-day period were also truly significant, they would not have been detectable without more replications.

Table 1 — Significance¹ of numbers and percent mortality of tussock moth larvae on treated plots of Douglas-fir, British Columbia

Dimilin treatment (oz a.i./gal)	Number of days postspray:					
	0	7	14	21	28	35
Mean number of larvae/1000 in²						
2.0	314	165	66	30	7	1
1.0	193	132	106	52	34	15
0.5	276	194	126	65	37	22
Untreated	155	130	86	89	72	60
Mean percent mortality						
2.0		49.9	79.4	91.4	97.9	99.7
1.0		31.3	46.2	73.9	82.1	92.2
0.5		36.3	61.0	75.8	86.1	89.7
Range		18.6	33.2	17.5	15.8	10.0

¹Means not connected by a bar are significantly different at the 95 percent level.

Regression of percent unadjusted mortality at 35 days postspray over ounces of Dimilin applied per acre indicates that 1.5-oz a.i./acre would have caused 93.5 to 97.5 percent mortality (*fig. 2*), and would have allowed a residual population of 4 to 15 larvae/1000 in² to survive (*fig. 3*). This degree of control may be inadequate during the rising phase of an outbreak to prevent substantial damage from occurring the following year. Therefore we recommend no less than 2.0-oz a.i./acre for control of rising tussock moth populations.

Defoliation of current-year needles occurred on most sample trees in all plots, but heavy losses of both new and old foliage occurred only on sample trees in untreated and 0.5-oz treated plots (*table 2*). Application of 1.0-oz a.i./acre may provide adequate foliage protection from collapsing larval populations, but probably not to treated stands containing a residual population of 10 to 21 larvae/1000 in² (*fig. 3*) with low levels of virus infection and parasitization.

Tussock moth populations in the Kamloops area collapsed by late summer of 1976. No egg masses were found on any of the experimental plots in October. A combination of virus, late larval and pupal parasitization, and adverse weather appeared to be the major

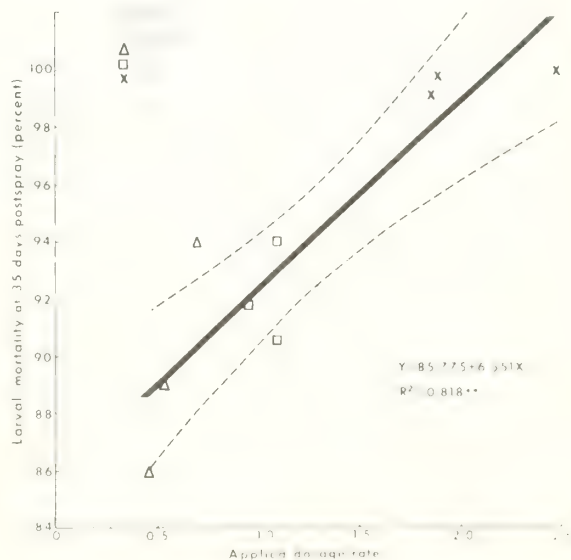


Figure 2—Douglas-fir tussock moth larval mortality, in mean percent per plot at 35 days postspray, is highest in plots treated with 2 ounces of Dimilin per gallon of spray. Applied dosage rate is calculated as a.i. applied per acre = (spray flow in gal) (oz a.i. per gal formulation)/ plot area in acres. Dotted lines show 95 percent confidence limits; ** = significant at 1 percent level.

cause of collapse of the outbreak. Watt (1968), in a computer analysis comparing tussock moth population fluctuations in interior British Columbia with weather variation, concluded that July and August mean temperatures were the first and second most important factors regulating tussock moth abundance there. Although the summer of 1976 was cooler than normal in Kamloops, exceptionally adverse weather did not occur until August (see Appendix, table 7). As the field test was terminated on July 23, we suspect that direct effect of adverse weather on differences among spray treatments was minimal.

Table 2 — Defoliation of Douglas-fir trees sampled on Dimilin treatment plots, British Columbia

Treatment (oz a.i./gal)	Number of trees showing complete defoliation of vertical length of crown shown:						
	None	Top 1/6	Top 1/3	Top 1/2	Top 2/3	Entire crown	All categories
2.0	72	3	0	0	0	0	75
1.0	75	0	0	0	0	0	75
0.5	63	5	4	3	0	0	75
Untreated	54	6	5	3	7	0	75

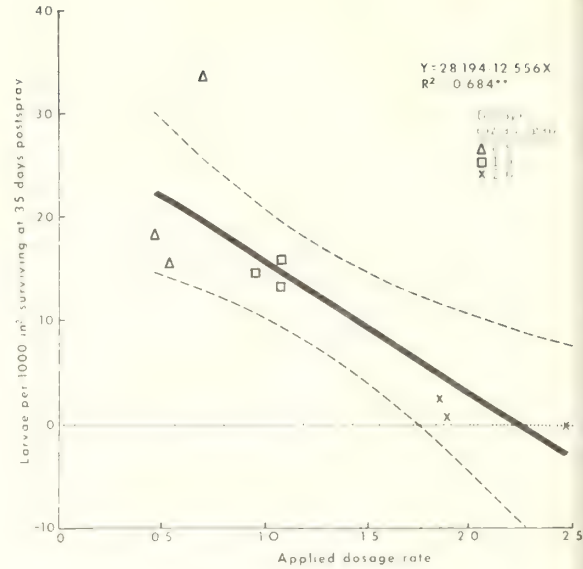


Figure 3—Mean number of surviving Douglas-fir tussock moth larvae/1000 in² per plot at 35 days postspray is lowest in plots treated with 2 ounces of Dimilin per gallon of spray. Applied dosage rate is calculated as in figure 2. Dotted lines show 95 percent confidence limits; ** = significant at 1 percent level.

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APPENDIX

Table 3—Summary of meteorological conditions in plots during spray application of Dimilin to Douglas-fir plots, British Columbia, 1976

Block	Date	Time	Sky	Temperature range		Maximum relative humidity	Wind speed	Airflow
				°F	°C	Pct.	Miles/hr	
1. N. Palmer-Forsyth	June 13	0500-0800	Overcast	45.0-50.0	7.2-10.0	60	3.0-6.0	Downslope
2. Dairy Creek	June 17	0530-0800	Clear	47.0-53.0	8.3-11.7	72	2.0-4.0	Downslope, then upslope
3. S. Palmer-Forsyth	June 18	0500-0730	Clear	52.5-56.5	11.4-13.6	77	2.0-4.0 ¹	Downslope

¹Air unstable early in morning, one 9-mi/h gust at 0515 on 1.0-oz treatment plot.

Table 4 — Aerial spray parameters and plot areas

Formulation (oz a.i./gal)	Date (June)	Swaths	Total spray time	Ground speed range	Fluid temperature	Pressure range	Flow range	Mean flow rate	Total flow	Plot area
			Min	Miles/hr	°C	Psi	Gal/min	Gal/min	Gal	Acres
2.0	13	12	3.72	90-123	36-42	40-57	20-23	20.3	75.6	80.0
2.0	17	13	3.33	90-120	38-42	38-52	19-22	21.7	72.4	78.0
2.0	18	13	3.55	105-132	42-45	36-52	20-24	20.6	73.0	59.0
1.0	13	13	2.95	90-120	34-40	45-61	21-25	22.4	66.2	60.8
1.0	17	13	3.27	99-126	36-46	40-51	20-23	21.3	69.6	73.0
1.0	18	13	3.43	90-138	38-46	40-54	21-24	21.7	74.3	68.1
0.5	13	13	2.93	81-134	34-38	49-65	21-24	22.2	65.1	61.1
0.5	17	12	3.05	102-129	36-42	54-62	24-26	24.6	75.0	80.7
0.5	18	13+	3.38	96-129	38-46	35-52	20-24	20.7	70.1	50.4

Table 5 — Sample spray deposit parameters, by Dimilin treatment

Treatment (oz a.i./gal)	Mean deposit and standard error ¹		
	Drops/cm ²	Volume median diameter (microns)	Gallons/acre
2.0	20.56 ± 0.54	269.6 ± 35.0	0.30 ± 0.10
1.0	22.51 ± 2.75	244.6 ± 39.3	0.22 ± 0.06
0.5	25.65 ± 7.34	174.7 ± 23.3	0.20 ± 0.11

¹Computed from three replicate averages per treatment.

Table 6—Probability of detecting a significant difference in mortality among Dimilin-treated plots, with treatments replicated three times¹

Percent difference in mortality to be detected		Probability at number of days postspray shown:				
Range	Deviation from mean	7	14	21	28	35
10.0	5.0, 0, -5.0	< 20	< 20	33	50	89
15.0	7.5, 0, -7.5	21	22	66	83	> 99
20.0	10.0, 0, -10.0	37	40	89	97	> 99
35.0	17.5, 0, -17.5	83	84	> 99	> 99	> 99

¹Outlined area shows that experimental power is high if the threshold for adequate power is arbitrarily set at 80 percent probability of detecting a significant difference.

Table 7 — Summer weather summary for Kamloops, B.C., 1976¹

Month	Temperature		Precipitation		
	Average	Deviation from normal	Total	Deviation from normal	Days with trace or more
	°C	°C	Mm	Mm	
June	16.2	-1.8	33.1	-3.2	13
July	19.6	-1.3	32.4	+6.5	12
August	17.5	-2.2	122.4	+95.5	21

¹Taken from Monthly Meteorological Summaries, Kamloops Airport, Environment Canada.

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RESPONSE OF VISITORS

to the

RAINBOW TRAIL:

an evaluation of an interpretive area in the

Lake Tahoe Basin, California

Richard A. Kusbyer

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RESPONSE OF VISITORS TO THE RAINBOW TRAIL: an evaluation of an interpretive area in the Lake Tahoe Basin, California

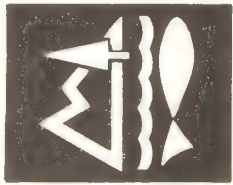
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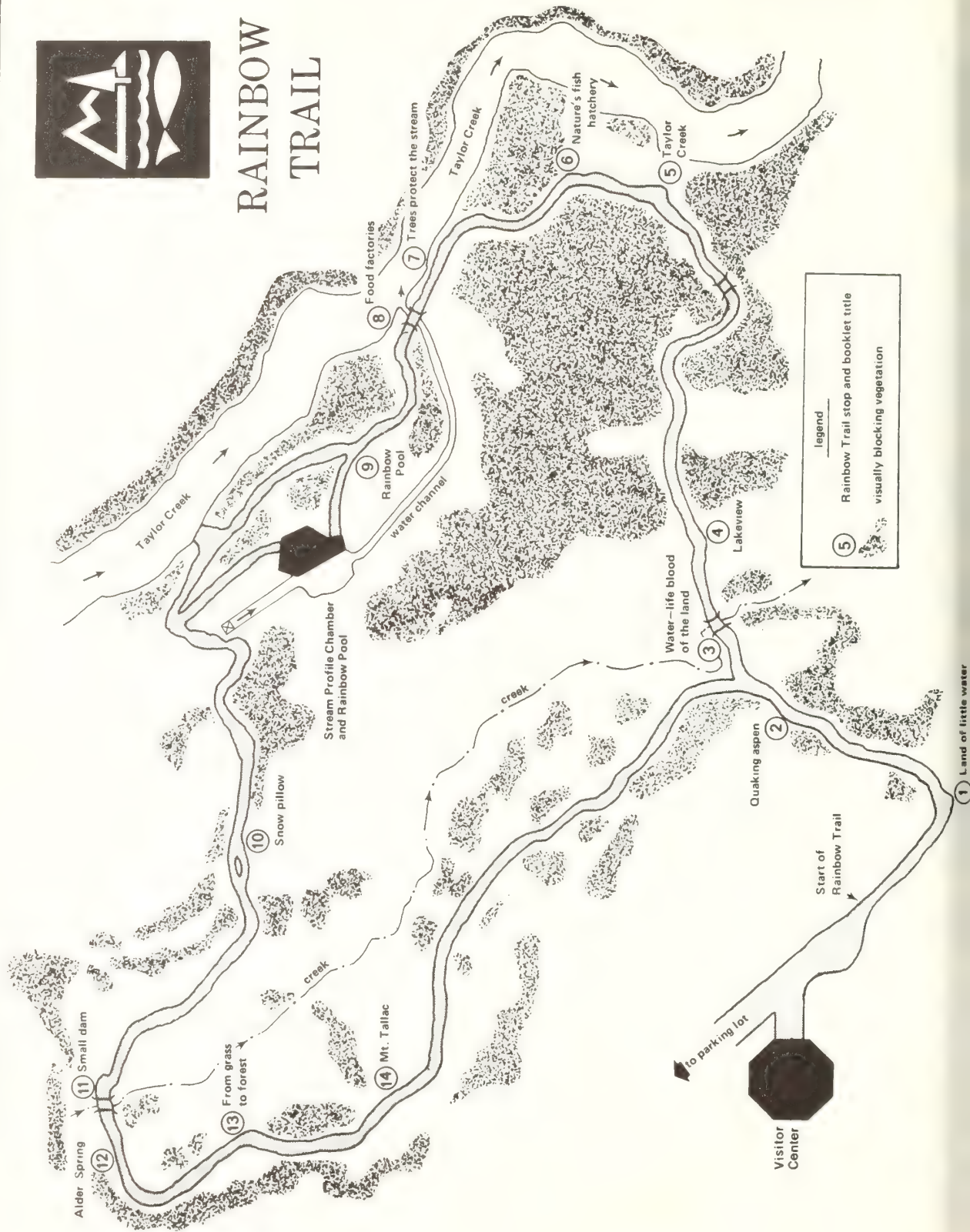
CONTENTS

	Page
Introduction	3
Methods	5
Site	7
Results	9
Demographic Information	9
Trail Behavior	11
Interview Responses	13
Learning	15
Conclusions	17

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RAINBOW TRAIL



Kuehner, Richard A., and Gary H. Elsner

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Retrieval Terms: outdoor recreation, interpretive trails, visitor behavior, interview surveys, Rainbow Trail, Lake Tahoe Basin, systematic observation surveys.

The behavior of 234 randomly selected visitors to the Rainbow Trail, a Forest Service Interpretive Area in the Lake Tahoe Basin, was surveyed by observation and by interview during the summer of 1971. The object of the study was to evaluate the success of the program in promoting enjoyment and learning in relation to the facilities provided and their cost.

Visitors tended to be well-educated California urban dwellers in their 30's or 40's who were on short trips with their children and who preferred comfortable accommodations and sedentary or moderately active forms of recreation. Their behavior on the trail was leisurely and somewhat passive: they read the material furnished them but usually did not participate in suggested learning activities; few took pictures.

Groups generally stuck together on the trail but dispersed in the Stream Profile Chamber, which contained under-surface observation windows and other displays. This fact may be related to the higher rate of learning on the trail than in the chamber. Overall,

enjoyment was high, and learning, while only moderate, exceeded the expectations of trail officials. Learning was higher among the better educated, the more physically active, and those who participated in the suggested activities.

The popularity of facilities such as the Rainbow Trail with a certain segment of the outdoor recreation population seems assured, but more needs to be done to promote learning — one of the primary goals of such areas. In particular, learning may be increased by maintaining group integrity and by encouraging active participation in educational activities rather than passive reading of information.

The visitor center, despite its purpose of providing visitors with follow-up educational material, played very little part in education, being used more as a source of administrative information. The expensive Stream Profile Chamber is probably worth its expense — but more as an attraction than as an educational facility.



RAINBOW TRAIL



LAKE TAHOE VISITOR CENTER ELDORADO National Forest

The numbered paragraphs in this leaflet correspond to numbered posts along the half-mile trail. Allow about one hour. Please help protect this meadow by staying on the trail.

The Rainbow Trail Booklet



1 LAND OF LITTLE WATER

Remember your first visit to a meadow of grass and boulders covered here by water from melting snow. Water from rain and snow quickly soaks through this rocky soil.

The plants that grow here are able to live in dry areas. As you walk along the trail, notice the sudden dramatic change in the kinds of leafy plants.

2 QUAKING ASPEN

The graceful Quaking Aspen grows only where ample soil moisture is present. The leaves quiver in the slightest breeze.

The magic of water abundantly available in the shallow root zone has created the windflower meadow just ahead.

3 WATER - LIFE BLOOD OF THE LAND

This small stream comes from springs in the meadow. The little dam was put across the stream to control soil erosion.

Each person in your home uses about sixty gallons of water every day. Would this stream supply the water your family needs?

Hold the gallon can under the stream of water flowing over the dam. How many gallons flow over the dam in one minute?

4 LAKEVIEW

To your right across the meadow, the blue water of Lake Tahoe is visible.

Probably at one time this meadow was a shallow arm of the big lake.

5 TAYLOR CREEK

To your right is Taylor Creek, one of sixty-three streams which flow into Lake Tahoe. Water from snow and rain falling on more than twelve thousand acres of National Forest and flows past this point.

Stop 6 is to your right on the bank of the creek.

6 NATURE'S FISH HATCHERY

Trout and Salmon deposit their eggs in deep beds of gravel covered with a thin layer of pebbles. Water circulates between the shells as spawning water oxygenates the eggs.

Nature's large pore spaces between the gravel particles in the spawning bed help the young fish.

7 TREES PROTECT THE STREAM

Look along the steep bank at your feet.

Notice how the roots bind the soil, holding it in place. When stream banks are washed away, mud and silt cover the gravel in the streambed.

Only covered eggs will not produce fish!

8 FOOD FACTORIES IN THE STREAM

These white water riffles in Taylor Creek are the home for large numbers of water insects. Water insects are the most important source of trout food.

As you visit the Rainbow Pool at the next stop, you will see a cross section of a stream the way it might look to a trout.

9 THE STREAM PROFILE CHAMBER

Displays inside the viewing chamber will tell the story of a trout stream and help you understand what you see through the windows.

10 SNOW PILLOW

The large pillow on the ground is filled with a non-freezing, poisonous liquid. The weight of the snow creates pressure in the liquid, which is reflected in a measuring gauge indicating the amount of water the snow contains.

In the higher mountains, most moisture falls as snow. The water snow contains is an important source of information regarding the amount of water stored in the mountains. This information is important to predict the water available for the next summer.

This small dam helps keep the meadow green! Behind the dam, water flows into the meadow at a grassy level. Below the dam, the water flows into a much lower level.

12 ALDER SPRING

The water that bubbles out of the ground here comes from rain and snow which fell on National Forest land nearby.

Loose, porous forest soil permits water to soak into the ground and reappear here. This is more desirable than having the water run



rapidly down steep bare slopes, carrying valuable topsoil into streams and lakes.

Jump high on the path and feel the solid ground shake. As you jump, watch the water in the pool to your right.

A few inches under the surface the soil here is completely saturated with water.

13 FROM GRASS TO FOREST

The meadow is a temporary and fragile part of the mountain environment. As small streams running through the meadow cut deeper they carry more water in the soil. As the soil becomes drier, forest trees invade the meadow and finally the meadow becomes a part of the surrounding forest.

The small pine trees growing in the meadow grass to your left indicate that this process is taking place here.

14 MT TALLAC - 9,735 FT

The tallest peak to your left is Mt. Tallac. This is one of the best known landmarks in the Lake Tahoe Basin.

Water from melting snow on Mt. Tallac flows through Taylor Creek and into Lake Tahoe.

We hope that you have found your walk on the Rainbow Trail worthwhile. The shimmering color of the rainbow are produced when sunlight is reflected from raindrops. We seldom see a rainbow but water touches the daily lives of all of us in many different ways.

Keep this folder if you wish, or return it to the Visitor Center so that others may use it.

The Viewing Chamber is open 9 a.m. to 5 p.m. daily during the summer season.

It is open Wednesday through Sunday 10 a.m. to 4 p.m. during the Klamath-Salmon spawning season, October 15 to December 1.

In recent years, the Forest Service, the National Park Service, and other outdoor recreation agencies have developed several programs aimed at interpreting the natural environment to the public. These public information programs—guided and self-guided nature walks and displays in visitor centers, for example—have been successful in attracting increasing numbers of visitors, but not much has been determined about the success of the programs in expanding the visitor's knowledge or in providing him with a satisfying experience. In the absence of measurable data about the visitor's learning and enjoyment, it has been difficult to make confident judgments about the level of expenditure which is justified for such projects.

The survey that is summarized here is an attempt to supply such measurable data—to analyze a particular recreation population (visitors to the Rainbow Trail) much as a marketing analysis would size up a prospective consumer group. But instead of trying to find out what these consumers would buy, we have tried to discover what they learned, whether they enjoyed themselves, how both enjoyment and learning were affected by features of the recreation program, and whether its results justified its cost.

This survey is a combination of interview and surreptitious observation—a combination since neither method alone seemed likely to yield results that would be simultaneously detailed and objective. The second method is seldom undertaken since it re-

quires long hours of close but unobtrusive observation of subjects actually engaged in some activity. This means a high investment of time and money per subject compared to questionnaire or interview surveys, but it also means particularly detailed results.

This paper is a summary of those results. A limited number of copies of a detailed but preliminary report¹ on the study were distributed by the Forest Service to interested State and Federal agencies in 1972. Some inconclusive or purely procedural information, which may possibly be of interest to some readers, has been omitted from this paper, but may be obtained from the authors or from the original report, of which a few copies are still available. Most points of major interest or importance, however, are given here in sufficient detail.

The illustrations accompanying the text of this paper have been designed to provide an overall view of the trail and its features. Selected photographs are keyed to the map of the trail and the illustration of the booklet format.

¹Kuehner, Richard A. 1972. *Visitors' behavior at the Lake Tahoe Visitor Center: a preliminary report of an observation and interview study of the activities of visitors on a Forest Service self-guided nature trail*. 172p. Unpublished report on file at Pacific Southwest Forest and Range Exp. St., Forest Serv., U.S. Dep. Agric., Berkeley, Calif. This research, designed and conducted by Richard A. Kuehner and analyzed by him and Gary H. Filsner, was part of a University of California, Davis study of the Tahoe Basin, financed by a grant from the National Science Foundation.



1.

LAND OF LITTLE WATER

Beneath your feet is a mass of gravel and boulders carried here by water from melting glaciers. Water from rain and snow quickly soaks through this rocky soil.

The plants that grow here are able to live in dry areas. As you walk along the trail notice the sudden dramatic change in the kinds of trailside plants.

2.

QUAKING ASPEN

The graceful Quaking Aspen grows only where ample soil moisture is present. The leaves quiver in the slightest breeze.

The magic of water abundantly available in the shallow root zone has created the wildflower meadow just ahead.

3.

WATER — LIFE BLOOD OF THE LAND

This small stream comes from springs in the meadow. The little dam was put across the stream to control soil erosion.

Each person in your home uses about sixty gallons of water every day. Would this stream supply the water your family needs?

METHODS

Information for this study was gathered by a combination of first-hand observation of visitors' behavior during the trail walk and interviews immediately following. These methods were intended to complement each other — the observations to record uninhibited behavior, the interviews to secure personal information and the impressions of the moment.

Subjects were randomly selected, alternately an adult male and an adult female, according to the order in which they crossed a certain line on the trail at certain times each day. By this method, about five visitors per day were surveyed on 42 days, equally divided among days of the week, throughout July and August of 1971, for a total of 234 visitors.

The observer was as unobtrusive as possible. Pretending to be a visitor, he followed the subject about, surreptitiously observing his behavior from a distance of 50 to 100 feet and making notes on the margins of a guide booklet, to be transferred to observation forms immediately after the walk. Behind his camera, the observer concealed a stop watch to determine the time the subject

spent at various stops. This procedure worked well and there was almost no danger of discovery. And since the visitor's name was unknown, his anonymity was protected.

As the subject neared the end of the trail, the interviewer, who had noted the visitor's appearance when he was selected, approached him and asked him to cooperate in a short (10- to 15-minute) interview. This personal request made it difficult for the subject to refuse: fewer than 10 percent of all subjects declined to be interviewed or left the area before they could be asked.

The interviewer worked from a set of prepared questions, asked in fixed order from the more general and open-ended to the more specific, and concluding with an invitation for suggestions. This order was designed to prevent the interviewer from influencing responses by indicating particular areas of concern prematurely. An effort was made, both in the wording of the questions and in the manner in which they were asked, to avoid betraying any personal point of view.

4. LAKEVIEW

To your right across the meadow the blue water of Lake Tahoe is visible

Probably at one time this meadow was a shallow arm of the big lake



5. TAYLOR CREEK

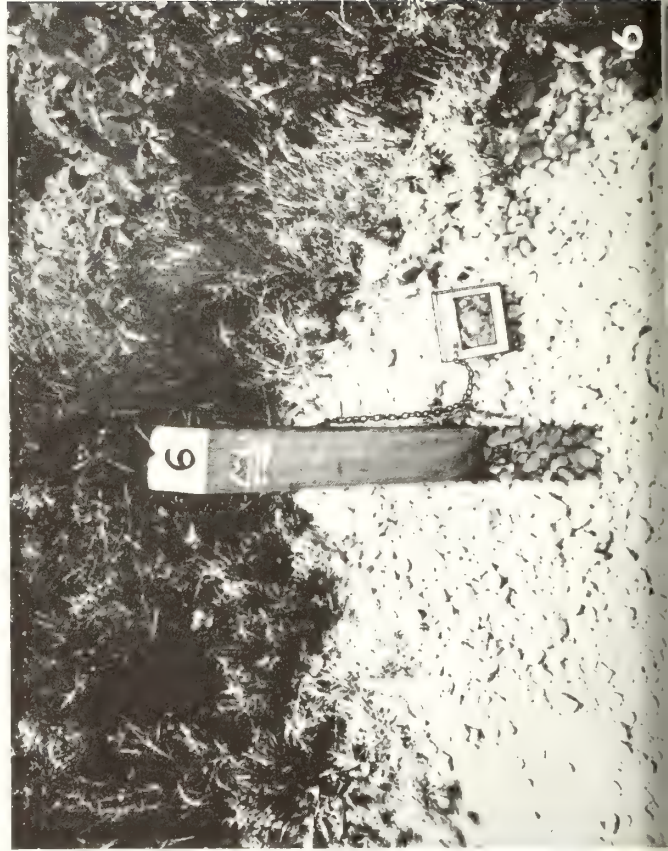
To your right is Taylor Creek, one of sixty-three streams which flow into Lake Tahoe. Water from snow and rain falling on more than twelve thousand acres of National Forest land flows past this point.

Stop 6 is to your right on the bank of the creek.

6. NATURE'S FISH HATCHERY

Trout and Salmon deposit their eggs in clean beds of gravel covered with a thin layer of pebbles. Water circulates between the pebbles carrying vital oxygen to each egg.

Notice the large pore spaces between the gravel particles in the sample attached to the post.



SITE

The Rainbow Trail is a part of the Lake Tahoe Interpretive Area — a Forest Service pilot study project located on the shores of Lake Tahoe. The trail winds through a meadow and along a perennial stream (Taylor Creek) in a loop six-tenths of a mile around (see p. ii). A visitor center at the entrance orients visitors to the theme of the trail — water quality and management — and provides them with guide booklets. These booklets are keyed to 14 numbered stops along the trail and give a brief summary of some educational point at each stop (see p. 2).

Midway around the trail is Rainbow Pool, with the Stream Profile Chamber (see p. 12). Here windows in an underground chamber permit observation of the life beneath the surface of the Rainbow Pool—observation which is augmented by recorded explanations of stream life through earphones located under the windows. Fourteen static displays provide additional information on the fish and their environment, on camera settings for photographing the fish, and on the various agencies that cooperate in the management of resources.



TREES PROTECT THE STREAM!

Look along the steep bank at your feet

Notice how the roots bind the soil, holding it in place. When stream-banks are washed away, mud and silt cover the gravel in the streambed.

Silt-covered eggs will not produce fish!

FOOD FACTORIES IN THE STREAM

These white water riffles in Taylor Creek are the home for large numbers of water insects. Water insects are the most important source of trout food.

As you visit the Rainbow Pool at the next stop, you will see a cross-section of a stream the way it might look to a trout.

SNOW PILLOW

The large pillow on the ground is filled with a non-freezing, poisonous liquid. The weight of the snow creates pressure on the pillow which is reflected in a measuring gauge indicating the amount of water the snow contains

In the higher mountains most moisture falls as snow. The water snow-pack is water stored for use the next summer. Information regarding the amount of water stored in the mountain snowpack is very important to predict the water available for the next summer.



RESULTS

Demographic Information

The typical visitor to the Rainbow Trail was an educated California urban dweller in his 30's or 40's who was on a short trip with his family and who preferred comfortable accommodations and sedentary or moderately active forms of recreation. Such a portrait, approximate as it is, suggests possible differences between trail visitors and the general population — even, perhaps, between trail visitors and other particular outdoor recreation populations.

The Rainbow Trail visitor was well educated. Nearly three-quarters had done some college work; nearly half had graduated (see p. 16). This is important because, as will be shown later, the well-educated learned more from the trail than the less-educated did.

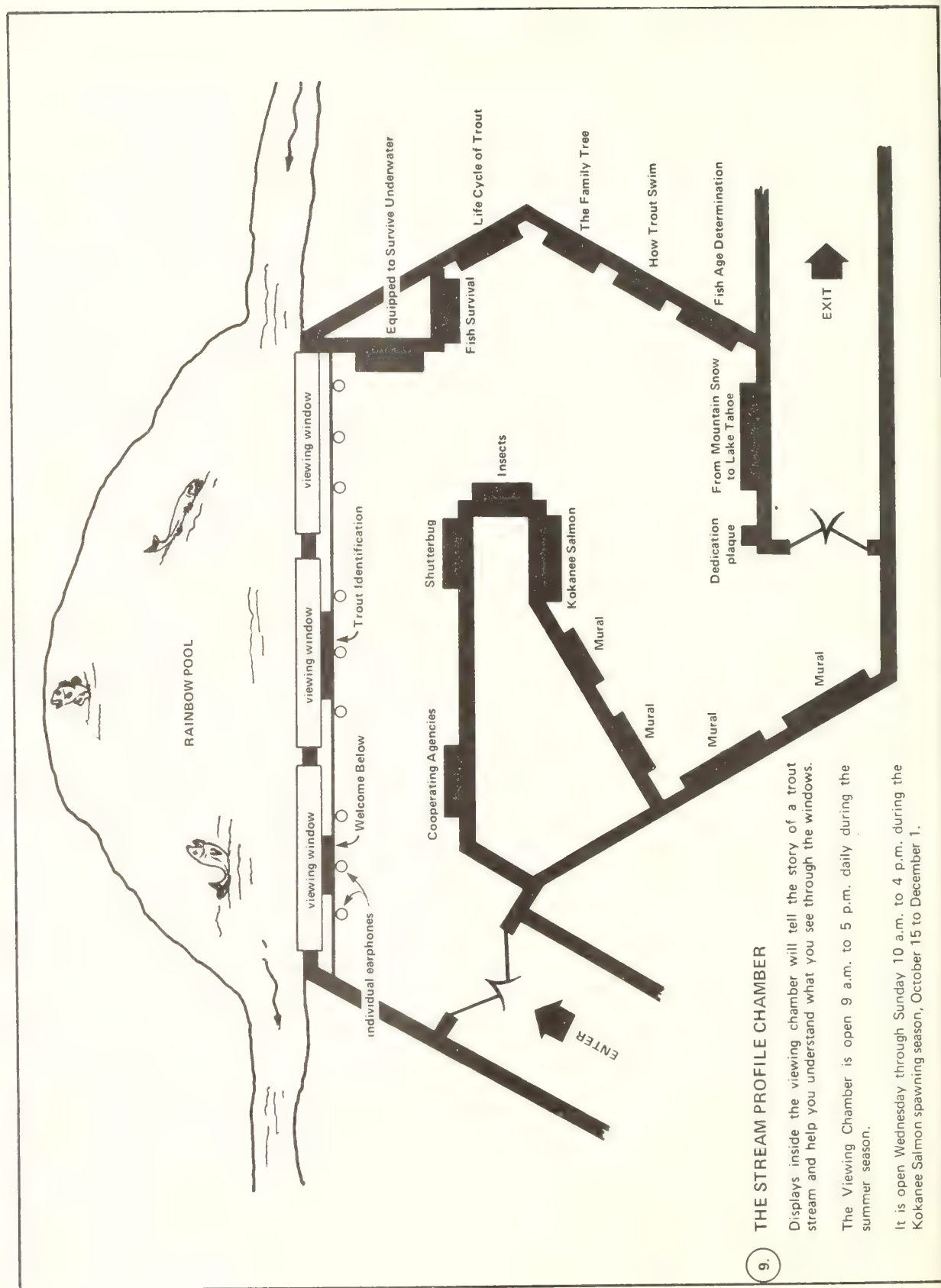
Eighty-three percent of visitors were Californians — even though the trail was located just a few miles from the Nevada border. Most were from the large urban areas in the Los Angeles Basin or around San Francisco Bay. Fifteen percent were relatively local residents — from El Dorado and adjacent counties.

Six out of ten visitors were between 31 and 50; two in ten were older and two were younger. This statistic does not include children, of course, since only adults were interviewed. But this age group would be expected to include parents of minor children, and, in fact, 63 percent of visitors were traveling with children — another fact with important implications about the desirable length, level of sophistication, and degree of stimulation of programs like the Rainbow Trail.

Almost all visitors were accompanied by someone else. Only 4 percent were traveling alone and more than half were traveling in groups of four or more. On the trail itself, most visitors were in groups; average group size was four. Apparently an interpretive walk is the sort of activity — like camping in public campgrounds — that derives some of its appeal from social contact.

On the other hand, interviews indicated the Rainbow Trail visitor's preference for more comfortable accommodations and relatively leisurely outdoor activity. When those who were staying in the Tahoe Basin (57 percent) were asked to specify their accommodations, six out of ten indicated hotels, motels, cabins, or houses, and two more indicated trailers or pickup campers. Only two out of ten camped. This might simply reflect the large number of comfortable accommodations and the relatively small number of campsites in the Tahoe area — but it might also mean that facilities like the Rainbow Trail attract many people who do not otherwise engage in outdoor activities. In either case, it is a significant finding, since trail officials had been aiming their advertising at nearby campgrounds.

When asked which other activities on our list they were participating in on this trip, most indicated "relaxing and sitting" and "sightseeing and driving for pleasure" (see p. 16). Though many were also hikers, campers, and fishermen, the most strenuous activity — backpacking — was the one least often indicated. An attempt to construct profiles of visitor groups according to the activities they engaged in proved inconclusive.



THE STREAM PROFILE CHAMBER

Displays inside the viewing chamber will tell the story of a trout stream and help you understand what you see through the windows.

The Viewing Chamber is open 9 a.m. to 5 p.m. daily during the summer season.

It is open Wednesday through Sunday 10 a.m. to 4 p.m. during the Kokanee Salmon spawning season, October 15 to December 1.

Trail Behavior

Use of the Guide Booklet

Seven out of eight groups picked up at least one guide booklet at the start of the trail. Two-thirds of all groups read the booklet at the indicated stops. In almost half the groups with children, an adult read portions of the book aloud. Occasionally this adult would editorialize — for example, by omitting the paragraph that suggested measuring stream flow (see booklet text, p. 2, item 3).

Reading of the booklet stayed at a fairly constant level throughout the 14-stop trail. Apparently this means that the trail was not too long to maintain interest and that the booklet itself was interesting and easy to read. There were, however, two sources of confusion in the booklet. The commentary on stop 5 said that stop 6 was located right — while actually it was to the left. Ten percent went right before discovering the mistake. The other problem was that part of the commentary on stop 12 — suggestion that visitors jump up and down on the trail and observe the effect upon the adjacent pool — was missed by some readers until too late because they did not follow the text from one page to another.

Time on the Trail

The average time spent on the trail was 30 minutes. As might have been expected, the largest proportion of time (7 minutes)

was spent in the Stream Profile Chamber, but if each of the 14 exhibit panels, 3 fish viewing windows, and 3 recorded messages is considered separately, then less time was spent per chamber exhibit than per trail stop.

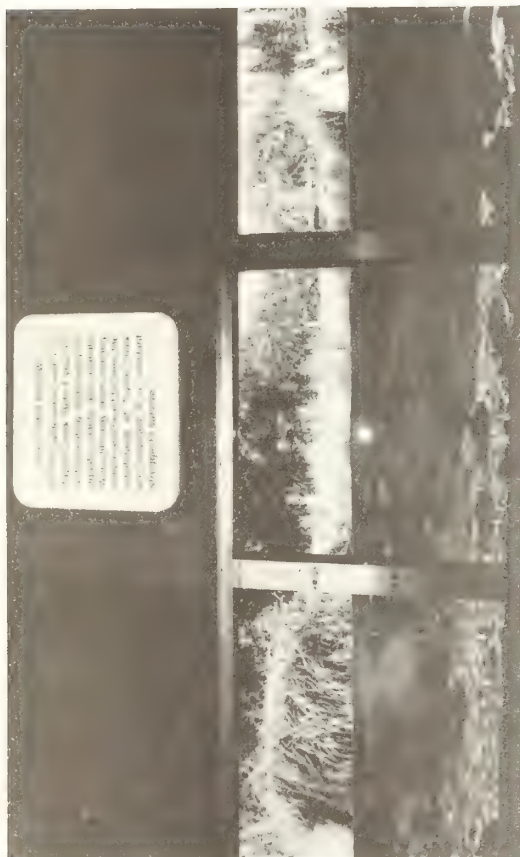
Use of the Stream Profile Chamber Displays

Most visitors (86 percent) listened to at least one of the recordings but few (17 percent) listened to all three. Observations and interviews suggested that the reasons for this sharp drop in interest in the recorded messages were occasional overcrowding at the limited number of earphones, the absence of any announcement that each bank of earphones offered a different message, and simple boredom (though each of the messages was less than 30 seconds long.)

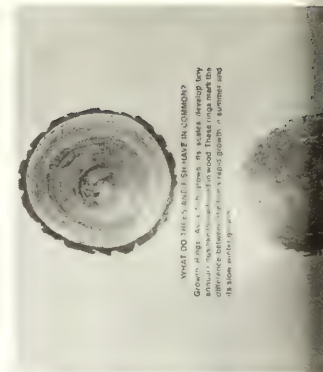
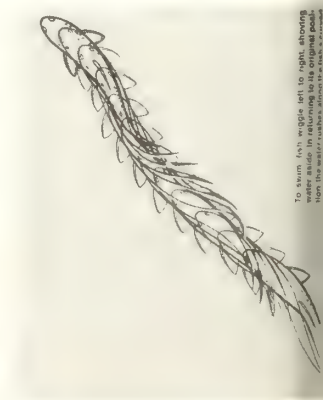
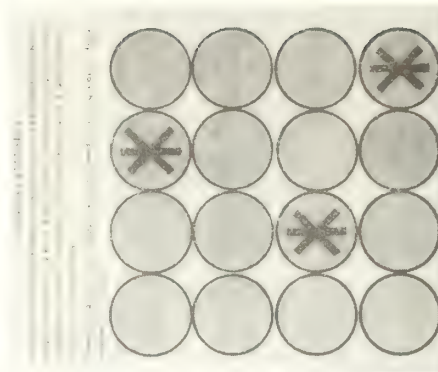
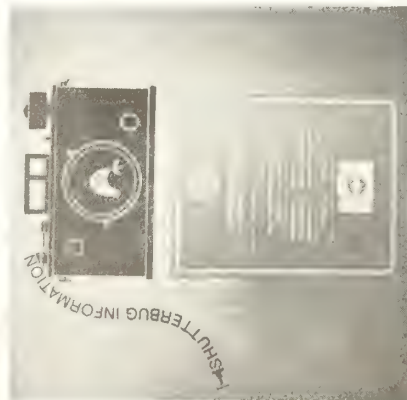
Visitor attention to the static displays was cursory and seemed to be related as much to the location of the display as to its content. Those that attracted least attention (shutterbug and agency displays) were directly across from the underground windows. Those that attracted most attention (insect and salmon displays) were along the shortest route out of the chamber.

Participation in Suggested Activities

Most visitors did not participate in the physical activities



Above, "Welcome Below" and "Trout Identification,"
Left, "Shutterbug" and "How Trout Swim"
Right, "Fish Survival" and "The Family Tree"



suggested to them by the guide booklet. Only 37 percent of all groups had a member who accepted the invitation to jump at stop 12. Only 19 percent stooped to pick up and examine a display of a typical fish-spawning bed seated in plastic.

Behavior at stop 3, where visitors were invited to measure stream flow using a gallon can, may provide an insight into the visitor's passivity. During the first month of the study, there was an old, rusty antifreeze can provided for this purpose. Only 14 percent of the visitors used it. But when it was replaced with a plastic sand pail, use increased to 26 percent. And when that in turn was replaced with a shiny steel bucket, use increased again to 35 percent. Apparently the steel bucket was more attractive, or less dangerous looking, or simply more visible than the rusty can.

Group Integrity

Along the trail itself, groups stayed together, reading the booklet or (occasionally) participating in suggested activities as a group. But when they entered the Stream Profile Chamber, groups larger than two tended to disperse, their members scattering to different windows or different displays and therefore keeping their observations to themselves. This dispersion increased when the chamber was crowded. Once back on the trail the groups reformed and continued as before.

Other Behavior Patterns

Use of Cameras — A third of all groups had at least one camera among them. But cameras were not used very much. Of those who carried cameras, about a third took no pictures on the trail and another third took only one. The rate of picture-taking inside the Stream Profile Chamber was even lower, despite the opportunity for taking close-up photos of live fish.

Vandalism — During the study, no vandalism and only two incidents of littering were observed.

Use of the Visitor Center — The visitor center was conceived by its designers as a place where visitors could get further information about subjects that they had become interested in through the displays or the guide booklet. But 90 percent of those who asked questions in the center asked questions unrelated to the theme of the trail — mostly about where they could camp or where the restrooms were.

Interview Responses

Thirty-nine percent of those interviewed said that some quality like "quiet" or "greenness" or "naturalness" was what they



12.

ALDER SPRING

The water that bubbles out of the ground here comes from rain and snow which fell on National Forest land nearby.

Loose, porous, forest soil permits water to soak into the ground and reappear here. This is more desirable than having the water run rapidly down steep, bare slopes, carrying valuable topsoil into streams and lakes.

Jump hard on the path and feel the "solid" ground shake. As you jump, watch the water in the pool to your right.

A few inches under the surface the soil here is completely saturated with water.

13.

FROM GRASS TO FOREST

The meadow is a temporary and fragile part of the mountain environment. As small streams running through the meadow cut deeper they lower the level of water in the soil. As the soil becomes drier, forest trees invade the meadow and finally the meadow becomes a part of the surrounding forest.

The small pine trees growing in the meadow grass to your left indicate that this process is taking place here.

14.

MT. TALLAC — 9,735 FT.

The tallest peak to your left is Mt. Tallac. This is one of the best known landmarks in the Lake Tahoe Basin.



liked best about the trail. Three-quarters said the best feature about the Stream Profile Chamber was the fish. This seems to indicate that visitors were seeking some confrontation with live nature — not simply with displays of natural phenomena.

Over half of the visitors said that they had not learned anything from the Stream Profile Chamber. Of those who admitted learning something, most indicated that they had learned from the displays. In contrast, six out of ten said they had learned something on the trail — mostly from the guide booklet. The most frequently mentioned lesson was the working of the snow pillow. Also mentioned were the ways that meadows give way to forests and the identity and environment of the quaking aspen.

Learning

Visitors were asked seven questions to test their knowledge of facts and concepts taught along the trail or in the chamber. Questions 1 to 5 pertain to matters discussed in the trail booklet, 6 and 7 to Stream Profile Chamber displays. Questions 1, 4, 5, 6, and 7 covered matters unlikely to be common knowledge or to be learned at other facilities in the Tahoe area. The results were as follows:

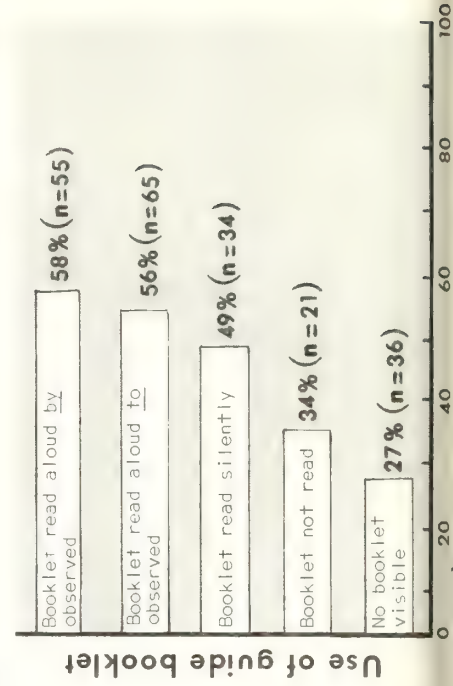
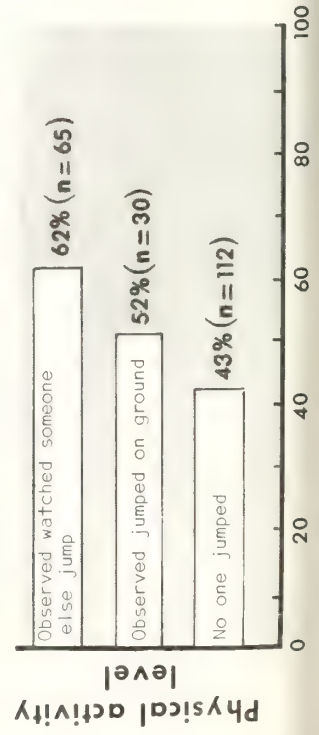
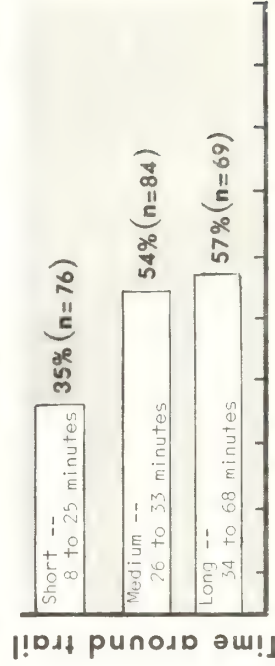
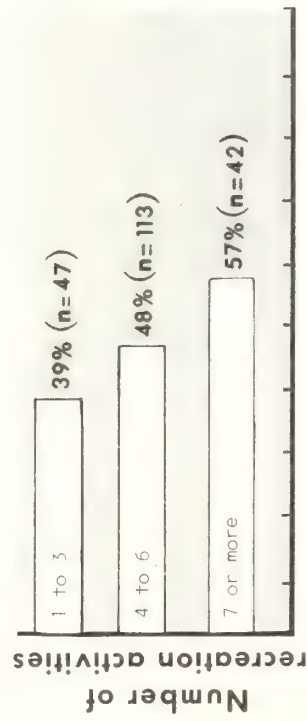
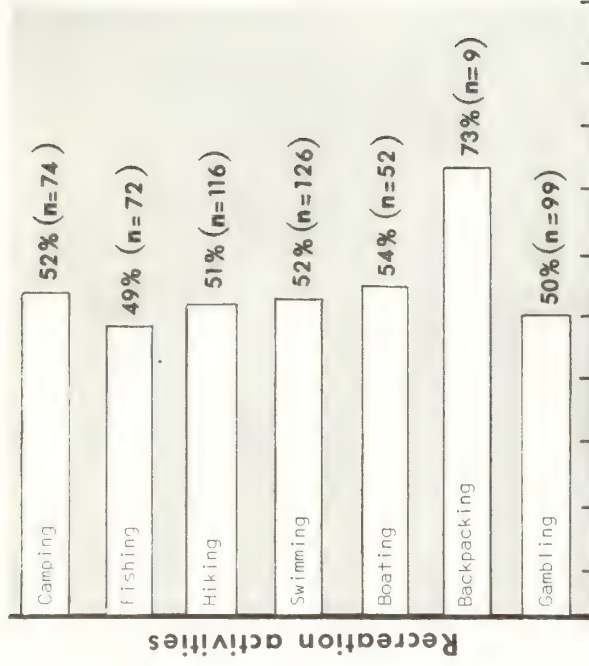
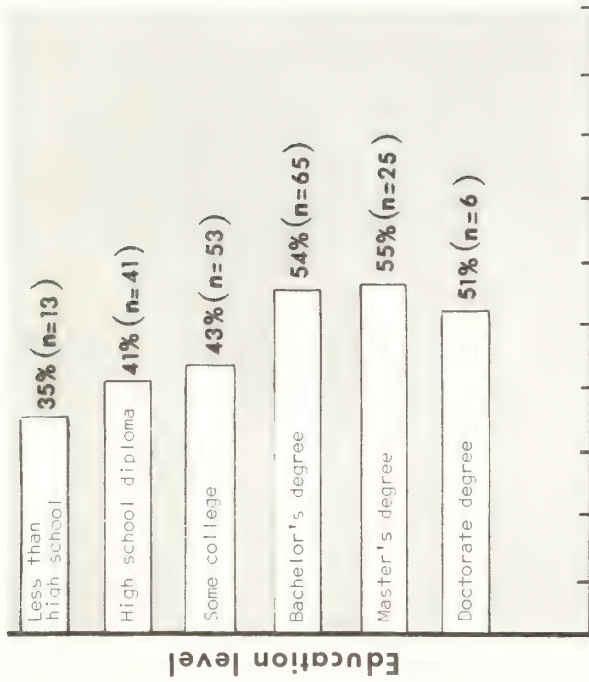
Subject of question:	<i>Correct</i>
1. Daily consumption of water	52

2. Identity of quaking aspen	81
3. Environment of quaking aspen	44
4. Purpose of the snow pillow	62
5. Effect of water quality on fish reproduction	18
6. Season of annual salmon run	36
7. Indicator of fish's age	47

These results surprised trail officials; they had not believed that visitors were learning this much.

Results were cross-tabulated with other information gathered by observation or by interview (see p. 16). As might have been expected, learning (or, at any rate, knowledge) was generally greater for the more highly educated, for back-packers, for those who had engaged in many activities while in the Tahoe area, for those who took their time on the trail, and for those who participated in the suggested trail activities. Learning was relatively unaffected by age, by the density of visitors on the trail, or by the size of the visitor's group.

Other interview questions established that most visitors recognized the Forest Service as the managing agency of the Rainbow Trail and that the trail sells itself, word of mouth providing more effective advertising than the official publicity then in use.



CONCLUSIONS

Visitors were generally impressed with the Rainbow Trail. They made few criticisms and their cheerful cooperation in the interviews (on the whole) implied their satisfaction. Yet most seemed unable to pinpoint the source of their good feelings. Perhaps they were just happy about being on vacation and would have been equally content with almost any recreation facility. For whatever reasons, it would appear that action on the findings of this study is not crucial to the continued satisfaction of Rainbow Trail visitors. But it may be highly relevant to the satisfactory realization of the goals of the designers and managers of the Rainbow Trail.

Designers of facilities like the Rainbow Trail ought to take the characteristics of the typical visitor into account — particularly his education, his preference for leisurely activity, and the likelihood that he is traveling with children.

Although Forest Service Visitor Information Service managers have expressed surprise that visitors learned as much as they did, more could be done to promote learning — learning is, after all, one of the primary goals of interpretive areas. Since this study shows that visitors who participated in the suggested activities along the trail learned more than those who did not, every effort should be made to encourage such activity. The replacement of the rusty antifreeze can with the shiny bucket is a case in point. Or the trail might be redesigned to direct the visitor's attention toward an activity and to make it harder for him to pass it by. For example, a well-marked one-foot drop in the trail at the point where the visitor is supposed to jump up and down might make it easier for him to comply without feeling self-conscious. Another finding that is relevant here is that those who went slowly learned

more than those who rushed around the trail. More activities and more attractive activities might arrest the attention of the speedier visitor and slow him down so that he could learn something.

Visitors acquired facts (like the identity of the quaking aspen) much more readily than they did concepts (like the requirements of the quaking aspen's habitat). Yet the concept is, of course, the more valuable information. A method needs to be found for presenting the more abstract ideas in a more tangible way.

The most expensive feature of the Rainbow Trail is the Stream Profile Chamber. Yet, despite the pleasure it gave visitors and despite the time they spent in it, they did not learn as much from it as from the guide booklet and from the trail itself. This may be related to the fact that groups tended to disperse in the chamber: learning may have been increased by the exchanges of observations which group members generally engaged in on the trail. If so, future facilities might be designed to maintain group integrity and privacy — perhaps by making the activities in the chamber more group-oriented or by opening the chamber up to avoid the "public" atmosphere of a closed room shared with other groups.

On the other hand, the time spent in the Stream Profile Chamber suggests that it is the real focus of interest on the Rainbow Trail. The enthusiasm which people seem to feel when they enter the chamber may be one reason that their groups disperse and their rate of learning slackens at that point. Though this study did not specifically indicate it, it may well be that the chamber is the reason people had come to the Rainbow Trail in the first place. If so, it may well be worth its expense as an attraction, even if not as an educational tool.



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PACIFIC SOUTHWEST Forest and Range Experiment Station



PONDEROSA PINE RESPONSE TO FERTILIZATION:

influence of brush
removal and soil type



Robert F. Powers

Grant D. Jackson



The Authors

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We are grateful to E. I. (Bud) Veirs and Duane Nebeker, who were stationed on the Eldorado National Forest at the start of this study, for their help in installing plots and treatments at Balderston Plantation.

Cover: Ponderosa pine growing with and without a brush understory at Balderston plantation. Manzanita biomass averaged nearly 30 tons per hectare (*lower right*).

MONTEREY PINE RESPONSE TO FERTILIZATION: influence of brush removal and soil type

Robert F. Powers

Grant D. Jackson

CONTENTS

	<i>Page</i>
Introduction	1
The Study Plantation	2
Methods	2
Plot Installation	2
Data Collection	5
Data Analysis	5
Results	6
Stem Growth	6
Foliar Traits	6
Discussion and Conclusions	8
Literature Cited	9

IN BRIEF...

Powers, Robert F., and Grant D. Jackson

1978. **Ponderosa pine response to fertilization: influence of brush removal and soil type.** Res. Paper PSW-132, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Oxford: 174.7 *Pinus ponderosa*:237.4:232.211 [—176.1 *Arctostaphylos* spp.]

Retrieval Terms: *Pinus ponderosa*; fertilization; weeding; soil fertility; Mariposa soil; Cohasset soil; manzanita.

Growth of forest stands is limited by the availability of moisture, nutrients, and light. These controlling factors are particularly evident in young plantations. There, fertility often is depressed if topsoil has been removed during site preparation. Frequently, trees in young plantations must compete for scarce site resources with invading brush species that aggressively colonize sites of recent disturbance. These conditions are favored by California's Mediterranean climate and by droughty, immature soils. Where such conditions occur, trees often are stunted. This paper describes an experiment aimed at improving growth of young, planted ponderosa pine through nitrogen fertilization and brush control on two soils of contrasting fertility.

In late 1975, study plots were established in the western foothills of the Sierra Nevada on two soil series—a fertile Cohasset, and a less fertile Mariposa—each supporting 9-year-old plantations of ponderosa pine and dense understories of whiteleaf manzanita. Brush was removed completely from half of the plots and plots were fertilized with urea at rates equivalent to 0, 224, or 448 kg N/ha.

Measurements and chemical analyses made after the next growing season showed that trees on the Mariposa soil were initially deficient in nitrogen, but that fertilization was not effective if brush remained in place. Where brush was removed, fertilization produced a doubling in height growth

and a major increase in foliar nitrogen content. Needles formed in 1976 were nearly twice as heavy on Mariposa plots free of brush as they were where brush remained. Fertilized trees on plots free of brush seemed to retain needles better. Results suggest that trees on the Mariposa soil made major gains in crown biomass.

Trees on the fertile Cohasset soil seemed to dominate the brushy understory, and height growth of pine was not improved significantly by any treatment. Foliar N concentrations generally increased with fertilization rate, whether brush was present or not. Foliar analyses of untreated trees indicated, however, that the supply of soil nitrogen was adequate for rapid growth, even without fertilization. Needles formed following treatment were about 40 percent heavier for trees on Cohasset plots free of brush than on plots where brush remained.

On the Mariposa soil, tree growth was limited severely by the scarcity of moisture and nitrogen, and to some degree, by reduced amounts of light. Brush removal, coupled with fertilization, caused major growth gains in the first year following treatment. Improvements in foliar biomass and nutrient content were noted for trees on the Mariposa soil—and to a lesser degree, for trees on the Cohasset soil as well. Resulting increases in photosynthetic area suggest that rapid growth rates will continue for treated trees.

Western forest managers are turning to intensive silvicultural practices in coaxing greater wood yield from a diminishing forest base. Generally, commercial yields can be improved through better stocking. But on many sites stocked adequately with trees, growth rates may be depressed because of poor soil fertility or competition from invading vegetation. Foresters need to recognize growth problems before they become severe, understand the conditions causing the problems, and choose appropriate treatments to correct them.

Competing vegetation often reduces growth in young stands of ponderosa pine, as demonstrated in various studies. Pole-sized trees on a dry site in northeastern California showed small but significant increases in 5-year basal area growth following removal of perennial grasses (Gordon 1962). Removing a brushy understory from a thinned stand of pine saplings on a dry, central Oregon site resulted in 4-year growth improvements of nearly 40 percent in diameter and 60 percent in height (Barrett 1965). Bentley and others (1971), studying a 5-year-old plantation near Mount Shasta, found trees growing free of brush to be about twice as tall as trees competing with manzanita (*Arctostaphylos* sp. Adan.) and ceanothus (*Ceanothus* sp. L.). Fago (1972) found that saplings and poles on Site I land of California's interior Coast Range had diameter increases 40 percent greater than controls in the 5-year period following removal of a dense manzanita understory. A similar study on Site II land in the California Cascades¹ reported height growth increases between 46 and 124 percent in the decade following release.

Information is emerging on nutritional characteristics of California forest soils (Jackson 1977, Powers 1977). Sites where surface soil has been removed during site preparation have the greatest potential for nutrient deficiencies. On poor sites, the top 10 cm

(4 in) may contain as much as one-third of the total soil reservoir of nitrogen, with the relative proportion decreasing as site quality improves (Powers 1976). Thus, scalping the surface soil to eradicate roots and seeds of weed species during type conversion may reduce nutrient availability and depress soil fertility, particularly on poor sites. As recently as 1959, the standard prescription for preparing certain brush sites for conifer regeneration was to bulldoze 45 to 60 cm (18 to 24 in) of surface soil from the regeneration site into windrows or terraces (Buck 1959). As a consequence, many young stands in California now show evidence of nutrient deficiencies because of past cultural practices.

Waring and Youngberg (1972) and Powers (1974¹) believe that nutrient deficiencies, fertilizer response, and site productivity pivot on interacting site factors of temperature, moisture supply, and nutrient availability, and that these key factors should be measurable. To develop the theory further, the Pacific Southwest Forest and Range Experiment Station and Region 5 of the Forest Service began in 1975 a 10-year cooperative program in forest nutrition research (Jackson 1977). Using one of our first field installations, we were able to study the interaction of fertilization with brush competition in a plantation on contrasting soils. We sought answers to these questions:

- How severely are young trees influenced by brush competition?
- Will nitrogen fertilization affect growth rates?
- How do trees react to the interaction of brush removal and fertilization?
- Do these effects vary with soil type?

This report documents early growth response of planted ponderosa pine (*Pinus ponderosa* Laws.) to brush removal and nitrogen fertilization on contrasting soils in the western Sierra Nevada. Results should help forest managers to prescribe silvicultural treatments in young stands.

¹ Powers, Robert F. *Determining site quality in California*. (Manuscript in preparation.)

THE STUDY PLANTATION

Balderston Plantation covers 32 ha (80 acres) and is located at 975 m (3200 ft) on the Georgetown Ranger District of the Eldorado National Forest in California. Relief is gentle, with a slight southern exposure. The climate is typically Mediterranean. Precipitation begins in late fall and averages 135 cm (53 in) annually, of which slightly more than half is snow. July and August are the driest months. Annually, an average of 48 days reach or exceed a temperature of 32° C (90° F). The mean number of days with temperature minima above freezing is 189.

Before 1966 the area was dominated by whiteleaf manzanita (*A. viscida* Parry) resulting from a 1947 burn. In 1966, brush was bulldozed into windrows spaced about 20 m (66 ft) apart. Notes were not taken at the time, but soil remaining in the windrows today suggests that only a few centimeters of topsoil were scalped from the planting surface. In spring 1967, ponderosa pine were planted at 2.4-m (8-ft) spacings and the area was sprayed the following year with 2,4,5-T to control reinvasion by brush. The herbicide treatment was ineffective, and by 1975 *A. viscida* again dominated much of the area.

Examination of the site in spring 1975 showed that the plantation overlapped two contrasting major soil series. One, the Mariposa, derived from metamorphosed Paleozoic marine sediments, is a fine-loamy, mixed, mesic, ruptic-lithic-xerochreptic Haploxerult. It is less than 1 m deep over fractured

schist. The Mariposa series is moderately acid, has gravelly silt-loam textures and is rated relatively low in timber productivity. The second soil, the Cohasset, derived from Pleistocene basic volcanics, is a fine-loamy, mixed, mesic, ultic Haploxeralf. It averages more than 1 m deep. The Cohasset series has loam/clay loam textures, is moderately acid, and is rated high in timber productivity. These series are similar in total amounts of nitrogen stored in their profiles; each averages slightly more than 5000 kg N/ha (4460 lb N/acre). They rank centrally in the array reported for California soils (Zinke and Stangenberger 1975). Total nitrogen storage is misleading, however, because nearly all the stored nitrogen is in the organic form, unavailable to higher plants. Of greater importance are differences between the series in rate of mineralization of organic nitrogen.²

The tallest planted trees on the Mariposa soil extended only half a meter above the brush, but on Cohasset the tallest trees overtopped the brush by more than a meter (*fig. 1*). Matured needles formed the previous season were sampled from dominant trees and analyzed for total N concentration by micro-Kjeldahl (Jackson 1958). Needles of trees on the Mariposa series tested 0.8 percent N on a dry-weight basis, and needles of trees on Cohasset tested 1.1 percent. Spring is a poor time for foliar sampling (Powers 1974). Nevertheless, we felt results suggested a nitrogen deficiency on the Mariposa soil (<1.0 percent) but no apparent deficiency on the Cohasset.

METHODS

Plot Installation

In July 1975, National Forest personnel established eighteen 0.04-ha (0.1-acre) plots on each soil series in a randomized block design, with three blocks of six treatment plots each. (One block was later omitted from data analysis because it had been inadvertently installed on a contact zone between the two soils.) Treatments were assigned as factorial combinations of dry, agricultural grade urea (46 percent N) at 0, 224, and 448 kg N/ha (0, 200, and 400 lb N/acre) and removal or nonremoval of competing brush. Hand tools were used the following month to remove brush from nine plots on each soil series (*fig. 2*). We established measurement plots of 0.01 ha (0.03 acres) within the boundaries

of the 0.04 ha plots. Trees in the measurement plots were separated from the outer plot boundaries by a 1- to 2-tree-wide buffer strip. Measurement plots contained an average of 16 trees.

In November 1975, following several weeks of scattered showers, urea was applied by hand to each plot. Temperatures were cool during fertilization and the warmest temperature in the 2 weeks that followed was 20° C (68° F). Precipitation continued intermittently for the next several weeks, with a total of 14 cm (5.5 in) in December.

² Powers, R. F. Unpublished data on file at the Pacific Southwest Forest and Range Experiment Station, Redding, California.



Figure 1—Manzanita competes strongly with trees for site resources at Balderston plantation. *Above*, planted trees are slightly taller than brush on the Mariposa soil series. *Below*, planted trees reach well above the brush on the Cohasset series.





Figure 2—Brush has been removed on the Mariposa series plot (*above*) and on the Cohasset series plot (*below*).



Data Collection

Following fertilization, all measurement plot trees were measured for total height to the nearest 3 cm (0.1 ft) and diameter at 30 cm (12 in) to the nearest 2.5 mm (0.1 in). Brush density was estimated by dropping a metal pin at systematic intervals along two line transects across each plot. The product of the proportion of "hits" to "misses," and the mean of vegetation heights at each point of pin contact, gave a cubic measure known from a previous study to correlate well with standing biomass of brush.²

In August 1976, at the end of the first growing season following treatment, composite samples were drawn from fully matured needles in the upper third of the crowns from three to five of the tallest trees in each plot. Needles formed during the current and previous year were sampled separately. Samples were refrigerated for laboratory analysis of total nitrogen by micro-Kjeldahl. The plots were revisited in September and the 10 tallest trees per measurement plot were selected for measurement of 1976 height increment and current diameter at 30 cm. The tallest trees were chosen for sampling because they generate the crown classes that produce future crop trees (Oliver and Powers 1971). Needle fascicles were removed from the central part of the main leader of each measurement tree and stored on ice for determination of fascicle lengths to the nearest millimeter (0.04 in) and dry weights to the nearest milligram. Additionally, in each plot, one branch was taken from the second-year whorl of a single tree that seemed representative of the measurement trees. Live needle fascicles remaining from the current and previous year were counted separately.

Data Analysis

The heights and diameters of plot trees in 1975, before treatment, were analyzed for variance. The analysis revealed highly significant differences between trees on the two soil series ($\alpha = 0.01$). Trees on the Mariposa series were less than two-thirds the size of trees on Cohasset nine growing seasons after planting. Variation in tree size on Mariposa was about half that on the Cohasset, although coefficients of variation for height were 17 percent on both soils. Whereas brush coverage was similar on each soil, manzanita was 39 percent taller on the Cohasset series, and standing biomass there was 44 percent greater (table 1).

Differences between blocks on the Mariposa soil series were not significant statistically. Block dif-

Table 1—Initial condition of vegetation on ponderosa pine plantation study plots, Eldorado National Forest, fall 1975

Soil series ¹	Trees		Brush ²		
	Total height	Diameter at 30 cm	Coverage	Height	Biomass
	Cm.		Pct.	Cm.	Tons/ha
Mariposa:					
Mean	113	3.5	56	54	19.5
S.D.	19.1	.65	10.9	4.1	3.94
Cohasset:					
Mean	191	5.4	58	75	28.0
S.D.	32.7	1.23	16.1	10.1	8.83

¹ Data cover 18 Mariposa plots and 12 Cohasset plots.

² Cover percentage (C) and height (H) were determined by point density estimates; biomass (tons/ha) = $0.581 + 0.0062CH$.

ferences were highly significant on the Cohasset series when all three blocks were included in the analysis, but not when the block installed on a contact zone was omitted. Data from this block are not reflected in analyses of results.

Main effects for all categories of data gathered in August 1976, after treatment, received preliminary screening by random block factorial analysis of variance. Where treatment effects were found significant at $\alpha = 0.10$ or less, treatments were tested orthogonally according to specific comparisons planned *a priori*. This is a sensitive test for describing general response surfaces through a limited number of comparisons. Further, it provides an effective test of treatment effects if response differences are small. Additionally, all treatment means were compared at $\alpha = 0.05$, using Duncan's New Multiple Range Test, allowing each treatment to be compared with every other.

RESULTS

Tree response to brush removal and fertilization was tempered by the soil series on which trees grew. Certain treatment combinations produced striking results on the Mariposa series, but changes on the Cohasset series were more subtle. Results can be separated into categories of stem growth and foliar traits.

Stem Growth

Separately, neither brush removal nor fertilization significantly affected height growth on Mariposa soil. But combining these treatments produced growth responses nearly double those on plots where either treatment had been applied (*table 2*). A strong quadratic component was found through orthogonal contrasts for height response to fertilizer rate on Mariposa soil, indicating that the major response was to 224 kg N/ha, and that the highest rate of fertilization had no further effect on growth. Height growth was unaffected by treatment on the Cohasset series.

Fertilized trees on Mariposa soil from which brush had been removed had diameters significantly larger ($\alpha = 0.05$) than those where brush remained. Again,

significant changes in diameter were only apparent when treatments were combined. Tree diameters on Cohasset soil were unaffected by treatment.

Foliar Traits

Fertilization had no significant effect on foliar N concentration for trees on the Mariposa series if brush remained on plots. Where brush had been removed, foliar N concentration increased linearly with fertilization rate in both current and older needles. Orthogonal tests of results on the Cohasset series showed that nitrogen concentration in 1-year-old needles increased significantly with fertilization rate ($\alpha = 0.01$), particularly where brush had been removed. But for current year's foliage, concentration increases were not quite significant at $\alpha = 0.10$ —probably because losing one treatment block decreased the sensitivity of the test. Removing brush from Cohasset series plots caused no significant change in the nitrogen concentration of current needles.

Brush removal on the Mariposa soil, separately or combined with fertilization, produced striking increases in needle length, averaging 47 percent for

Table 2—Chemical and physical properties¹ of trees on the Mariposa and Cohasset soil series on ponderosa pine plantation plots at Eldorado National Forest, the first growing season after brush removal and fertilization, August 1976

Treatment	Foliar nitrogen		Height increment	Diameter (30 cm)	Current needle fascicles		Needle fascicles per branch	
	Current	1 yr old			Length	Weight	Current	1 yr old
	<i>Pct</i>			<i>Cm</i>	<i>Mg</i>			
	Mariposa series							
Brush present:								
0 kg N/ha	0.82a	0.80a	12.5a	4.5a	14.0a	140a	82a	91a
224	.82ab	.90ab	15.7a	5.0a	14.9a	168a	115ab	93a
448	.90ab	.91ab	14.7a	4.7a	14.5a	163a	58c	69a
Brush absent:								
0	.77ab	.70c	16.5a	4.9ab	21.2b	251b	86a	55a
224	.98b	1.03bd	29.8b	6.8c	24.0c	321c	160d	139a
448	1.22c	1.24d	28.1b	6.2bc	24.7c	356c	138bd	111a
	Cohasset series							
Brush present:								
0	.92a	.91a	41.1a	8.5a	20.8a	262a	174a	154a
224	1.14a	.95a	51.1a	9.2a	20.4a	250a	174a	158a
448	1.22a	1.30b	42.0a	9.1a	21.3a	242a	222a	142a
Brush absent:								
0	.90a	.87a	45.5a	9.3a	22.8a	326b	164a	184a
224	1.16a	1.30b	52.0a	9.6a	25.5a	377b	190a	151a
448	1.24a	1.22b	43.2a	7.9a	24.0a	356b	171a	168a

¹ For each soil series, within-column values not designated by the same letter are significantly different at $\alpha = 0.05$ by Duncan's New Multiple Range Test.

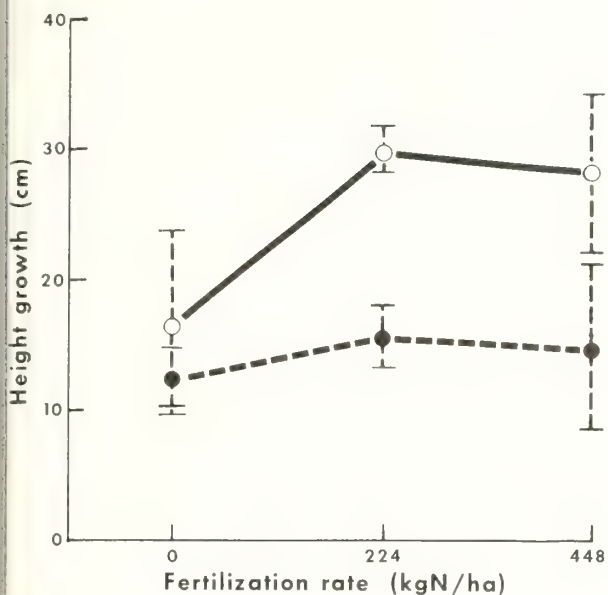


Figure 3—Height growth increased sharply for nitrogen fertilized trees on Mariposa soil series plots from which brush had been removed (solid line). Height growth varied little with fertilization rate on plots where brush remained (broken line). Vertical bars bracket 95-percent confidence intervals for treatment means (open and solid circles).

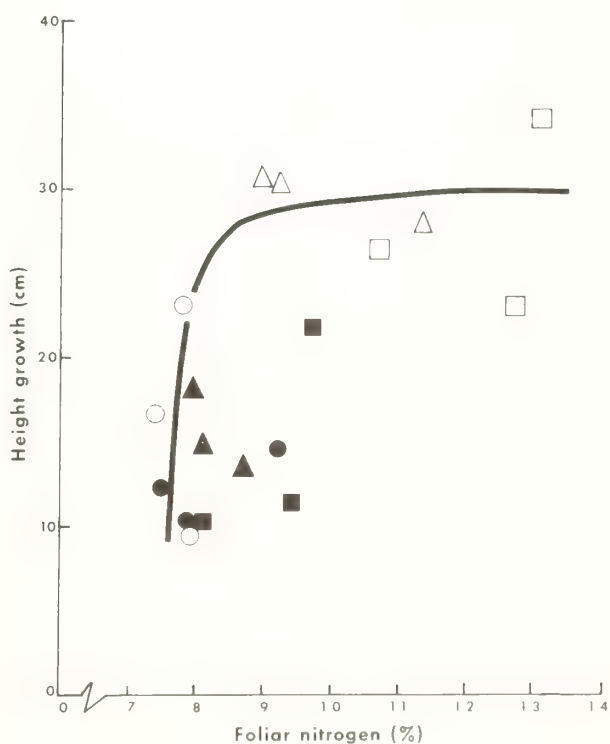
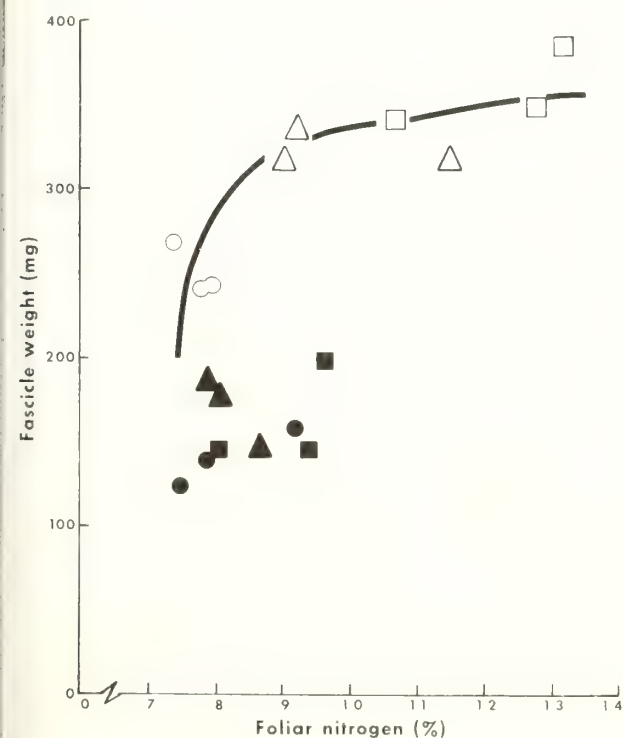


Figure 4—Growth increased sharply with foliar nitrogen content of trees on Mariposa soil series plots where brush had been removed (open symbols). Where brush remained (solid symbols), foliar nitrogen varied little and growth remained poor. Fertilizer rates were 0 (circles), 224 (triangles), and 448 (squares) kgN/ha. Trend curves are shown for brush-free plots.

brush removal alone, and 68 percent when combined with fertilization (*table 2*). No significant differences were detectable between the rate effects of 224 and 448 kg N/ha. Though needles of Cohasset trees were longer on plots from which brush had been removed, differences were small and not statistically significant.

Dry weights of 1976 needle fascicles were increased for trees on both soils following brush removal. Weight gains averaged 60 percent on the Mariposa series and 40 percent on Cohasset. Combining brush removal with fertilization on the Mariposa soil increased fascicle dry weight by nearly 120 percent. No difference was apparent between ferti-

lization rates—224 kg N/ha was as effective as 448 kg N/ha, and neither were effective where brush remained. Fascicle weights for trees on the Cohasset series were not affected significantly by fertilization.

Treatments had no discernible effect on the retention of needle fascicles formed the current year on the Cohasset soil, or the previous year on either series. Our sampling intensity (one branch per plot) was insufficient for the variation we found. However, combining brush removal with fertilization on the Mariposa soil resulted in significant gains in current-year fascicles remaining in September. Where brush remained, the heaviest fertilization rate seemed to decrease fascicle numbers.

DISCUSSION AND CONCLUSIONS

Climatic conditions affecting the 1976 growing season provided a strong test of brush competition for soil moisture at Balderston. Weather records at the Georgetown Ranger Station 4.8 km (3 miles) to the west of the study site show that the 1975-76 hydrologic year was the driest in over 20 years, with precipitation only 46 percent of normal. State-wide averages for the two soils (Zinke and Stangenberger 1975) show that the Cohasset series has the potential for holding 40 percent more plant-available moisture, and four times the exchangeable cations than has the Mariposa series. Undoubtedly, nutrient and moisture availability—and probably the shade cast by manzanita—affected tree growth on the Mariposa series more severely than on the Cohasset.

First-year results at Balderston plantation show that brush had suppressed the growth of pine seedlings severely on the Mariposa soil series. Though trees there clearly were deficient in nitrogen, brush competition circumvented growth response to fertilization. Where brush was removed, height growth increased, peaking on plots receiving 224 kg N/ha (*fig. 3*). Similar fertilizer rates have produced good growth response in a variety of species (Powers 1974). Combining fertilization with brush removal raised foliar N concentration above the critical level for ponderosa pine — 0.85 percent N,³ and contributed to a doubling of both height growth and needle weight (*fig. 4*). Gains in foliar biomass and nutrient content of trees on Mariposa series plots

indicate that improved growth rates will continue.

Growth on the Cohasset series was not limited by nitrogen availability, for unfertilized trees contained foliar N concentrations greater than critical level (*table 2*). But whereas trees on Cohasset plots clearly dominated the manzanita understory, growth was limited to some extent by moisture supply. Although heights and diameters were not influenced by brush removal, needle weights were increased 40 percent by this treatment. Gains in foliar biomass on brush-free Cohasset plots suggest that improved growth rates will follow.

On both soil series, removing brush on unfertilized plots resulted in small decreases in the concentration of foliar N in current and older needles (*table 2*). This can be explained by the “dilution effect” (Ulrich 1948) resulting from major changes in the biomass of current needles and little or no change in their nutrient supply. Differences great enough to be significant statistically were found only for older foliage on the Mariposa series. Coupled with brush removal, fertilization increased greatly the quantity of nitrogen stored in the standing biomass of trees on both soil series. Luxury amounts of nitrogen contained currently in widely spaced trees will supplement demands made on soil nitrogen once crowns close. Thus, high growth rates will continue even if soil nitrogen availability should diminish.

The key to increasing forest yields is our ability to identify the primary factors limiting growth. Coordinated research in forest nutrition is providing a framework for recognizing the controlling factors of temperature, moisture and nutrient supply, and linking them with silvicultural prescriptions for sustaining or enhancing forest growth.

³Powers, R. F. Unpublished data on file at the Pacific Southwest Forest and Range Experiment Station, Redding, California.

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represents the research branch of the Forest Service in California and Hawaii.

Powers, Robert F., and Grant D. Jackson.

1978. **Ponderosa pine response to fertilization: influence of brush removal and soil type.** Res. Paper PSW-132, 9 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

First-year results of fertilization in a young ponderosa pine plantation on two contrasting soils were analyzed. Trees testing low in foliar nitrogen responded strongly to fertilization where brush had been removed, but failed to respond if brush remained. Height growth was doubled by certain treatment combinations on the less fertile Mariposa soil, but was not influenced by treatment on the more fertile Cohasset. Brush removal increased needle weight for trees on both soils. Increases in foliar biomass and nitrogen content of trees on treated plots suggest that rapid growth rates will continue.

Oxford: 174.7 *Pinus ponderosa*:237.4:232.211 [—176.1 *Arctostaphylos* spp.]

Retrieval Terms: *Pinus ponderosa*; fertilization; weeding; soil fertility; Mariposa soil; Cohasset soil; manzanita.

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PACIFIC SOUTHWEST Forest and Range Experiment Station

U. S. FOREST SERVICE
DEPARTMENT OF AGRICULTURE

GROWTH MODELS FOR PONDEROSA PINE: I. Yield of unthinned plantations in northern California

William W. Oliver

Robert F. Powers



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CONTENTS

	Page
Introduction	1
The Plantations	1
Methods	2
Field Procedures	2
Office Procedures	3
Testing the Model's Predictive Ability	9
The Yield Tables	11
Mean Stand Diameter	11
Basal Area	11
Cubic Volume	11
Literature Cited	11
Appendix	12

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IN BRIEF...

Oliver, William W., and Robert F. Powers.

1978. **Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California.** Res. Paper PSW-133, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Oxford: 174.7 *Pinus ponderosa* — 566 [+612]

Retrieval Terms: *Pinus ponderosa*; plantations; growth models; yield tables; basal area; volume; northern California.

Yields of unthinned ponderosa pine (*Pinus ponderosa* Laws.) plantations with high initial survival, negligible brush competition, and low mortality from external causes were estimated by a growth model. Data were obtained from 367 trees in 12 plantations in the southern Cascade Range, northern Sierra Nevada, Klamath Mountains, and Warner Mountains of northern California. Sampled plantations represented a wide range of initial spacings — 3 by 3 feet to 12 by 12 feet (1 by 1 m to 3.7 by 3.7 m) and site indices from 35 to 120 feet (10.7 to 36.6 m) at 50 years total age (Powers and Oliver 1978).

Plantation yields were determined from stem analyses of individual trees by this procedure:

1. For each of four crown classes, the linear relationship of d.b.h. to the product of spacing and height above breast height was determined.

2. Heights of dominant trees were obtained from site index curves (Powers and Oliver 1978). Heights of codominant and intermediate crown classes were obtained from equations relating their heights to those of dominant trees (Oliver and Powers 1971). The relationship of suppressed to dominant tree height was estimated.

3. To obtain stand yields, curvilinear relationships between crown class proportions and the product of trees per acre and dominant height were determined.

4. Number of trees was reduced initially by 15 percent to account for mortality from planting shock. Mortality from intertree competition was distributed by crown classes after a maximum stand density was reached.

5. The following cubic volume equation was devel-

oped because existing volume tables were inaccurate for plantations:

$$V = 0.024843 + 0.0017645 D^2H$$

in which

V = Volume in cubic feet inside bark from 1-foot (0.3-m) stump to tip

D²H = the product of d.b.h. squared and total height.

6. The net cubic volumes that resulted were smoothed by four spacing-dependent equations.

Tables showing diameter, basal area, and net cubic volume yields by Site Indices₅₀ 40 through 120 were compiled for stands ranging in age between 10 and 50 years and in spacing between 6 by 6 and 12 by 12 feet (1.8 by 1.8 and 3.7 by 3.7 m). Also reported are diameter distributions by crown classes and stem volumes in cubic feet.

Model predictions were compared with observations from real stands. The model explained the following percentages of variation — 89 percent about the mean diameter, 78 percent about the mean basal area, and 92 percent about the mean cubic volume per acre. We were disappointed that the model underestimated net cubic volume per acre. Predicted volume averaged 187 cubic feet less than observed — a significant difference. Six of the 35 plots in real stands were from the only plantation in the Warner Mountains, however. Volumes were underestimated for all six plots. When they were excluded, the difference between predicted and observed volumes was not significant, and the number of over- and underestimated volumes was more nearly equal.

Ponderosa pine (*Pinus ponderosa* Laws.) has been planted extensively for timber production in northern California. In the last 15 years the Forest Service, U.S. Department of Agriculture, alone has planted more than 130,000 acres (53,000 ha).¹ Most of these plantations are managed intensively yet growth and yield information is inadequate — especially for plantations growing on highly productive sites. Lack of reliable data on plantation development on different site qualities at different initial spacings hinders important management decisions, such as choice of initial spacings, thinning schedules, and brush control strategies.

Simulated yields for high-survival plantations developing with little brush competition or disturbance

often are greater than those found in practice, especially over large areas. Inclusions of nonproductive areas, irregular spacing, and steep slopes can reduce yields (Bruce 1977). Nevertheless, these data provide both a standard with which to compare the effects of management decisions, and a performance goal.

This paper suggests the yield potential of unthinned ponderosa pine plantations with high initial survival, negligible brush competition, and low mortality from external causes. It is the first of three reports on growth models for ponderosa pine. The second report will examine the maximum growth potential of the species, and the third, stem and crown growth of individual trees in plantations.

THE PLANTATIONS

Yields were derived from 367 trees in 12 plantations in the southern Cascade Range, northern Sierra Nevada, Klamath Mountains, and Warner Mountains (Basin and Range Province) of northern California (table 1, fig. 1). Sample trees were measured in plantations which had (a) high initial survival, (b) closed canopies, (c) regular spacing, (d) negligible insect, disease, or storm damage, (e) no thinning, and (f)

negligible brush competition. Plantations ranged in age from 16 to 50 years, in d.b.h. from 4 to 13 inches (10 to 33 cm), and in height from 17 to 69 feet (5 to 21 m). Sampled plantations represented a wide range of initial spacings — 3 by 3 feet to 12 by 12 feet (1 by 1 m to 3.7 by 3.7 m) and site indices from 35 to 120 feet (10.7 to 36.6 m) at 50 years total age (Powers and Oliver 1978).

¹Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

Table 1—Characteristics of ponderosa pine plantations sampled for yield model

Plantation	Province	Elevation		Age	Site Index ₅₀		Spacing		Trees sampled
		(Ft)	(M)		(Ft)	(M)	(Ft)	(M)	
1-Shasta Lake	Klamath Mtns.	1700	518	34	40-55	15	8	2.4	30
2-Henry's Find	Cascade Range	3800	1159	46	75	21	8	2.4	20
3-Show	Cascade Range	3900	1190	50	75	23	12	3.7	38
4-Shingletown	Cascade Range	3600	1098	25	70	21	7	2.1	30
5-Sugar Hill	Basin and Range	5400	1647	38	35-55	11-17	8-9	2.4-2.7	60
6-Quincy	Sierra Nevada	3400	1037	28	35	11	3	0.9	30
7-Bloody Run	Sierra Nevada	4400	1342	21	100	30	7	2.1	30
8-Elliot Ranch	Sierra Nevada	4000	1220	20	105	32	7	2.1	30
9-Hazel Valley	Sierra Nevada	2800	854	16	105	32	6	1.8	10
10-Fraser Flat	Sierra Nevada	4900	1494	29	70-80	21-24	7	2.1	29
11-Wright's Creek	Sierra Nevada	4800	1464	18	100	30	7	2.1	30
12-The Basin	Sierra Nevada	3500	1068	16	90-120	27-37	4-5	1.2-1.5	30

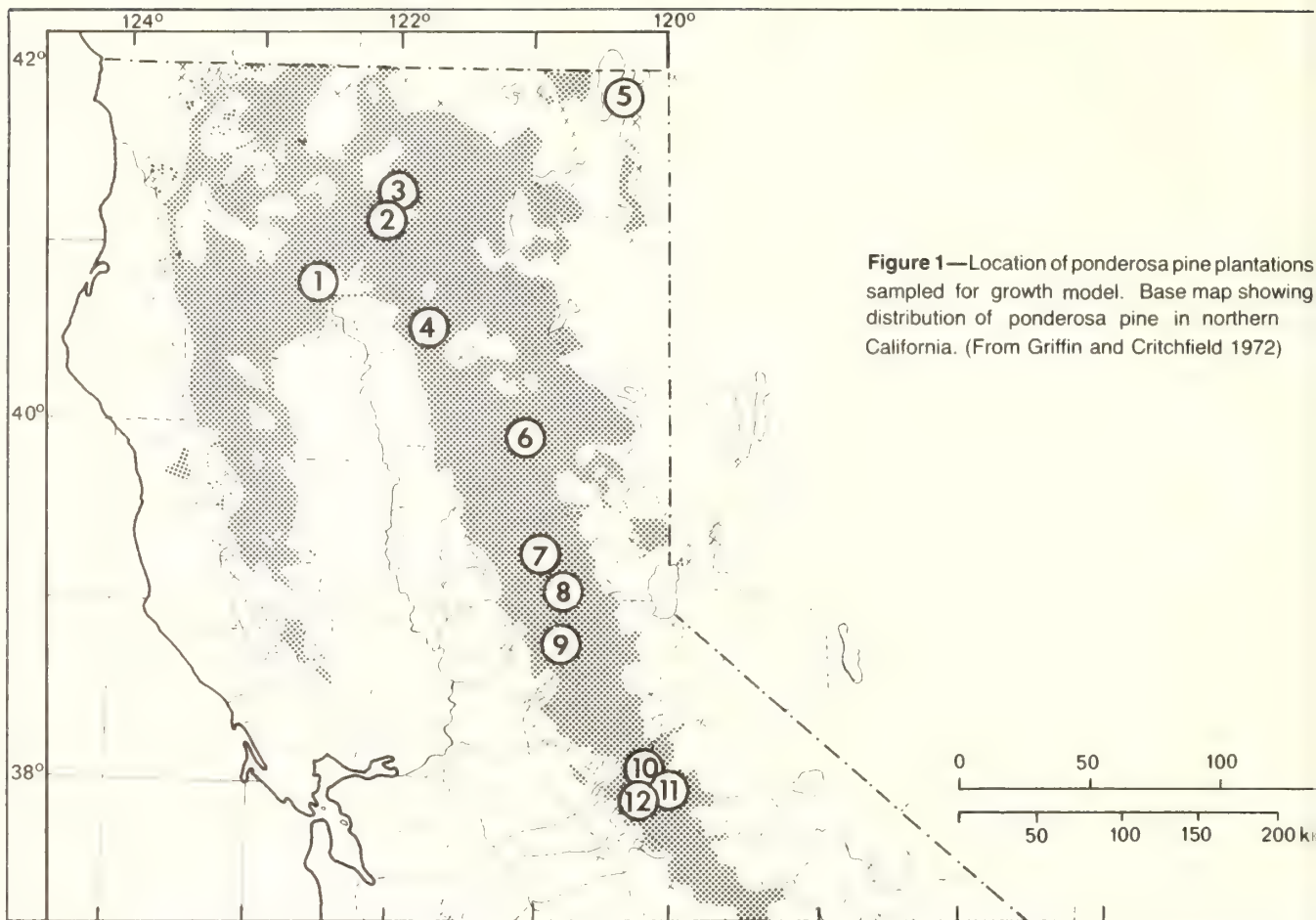


Figure 1—Location of ponderosa pine plantations sampled for growth model. Base map showing distribution of ponderosa pine in northern California. (From Griffin and Critchfield 1972)

METHODS

Field Procedures

Yield

At least 10 trees, representing about equal numbers of dominant, codominant, and intermediate crown classes, were selected for detailed measurements within a 0.05- to 0.1-acre (0.02- to 0.04-ha) area. Some trees within these areas were rejected because of damage or irregular spacing. From one to five of these 10-tree clusters were measured in each selected plantation. Data recorded for each tree were:

- a. Age from planting
- b. Crown class
- c. D.b.h. to nearest 0.1 inch (0.25 cm)
- d. Distance to nearest 0.1 foot (0.03 m) to adjacent trees both within and between rows

e. Past diameter and height for the first 10 years after reaching breast height, at 5-year intervals thereafter, and at present.

Ages from time of planting were determined from records. Ages of two plantations that had no records were estimated by adjusting breast height age from increment cores by years to reach breast height (Oliver and Powers 1971).

Past diameters were determined from annual ring patterns of three increment cores extracted in a flat spiral pattern at 120° intervals around the stem at breast height (Powers 1969). Past heights were measured at branch whorls with a graduated pole for trees up to 40 feet (12 m) in height. Taller trees were measured with a clinometer.

Volume

We developed a cubic volume equation specifically for plantation-grown ponderosa pine because existing volume tables were inaccurate for plantations. Data came from 425 trees which included 117 trees in nine of the 12 plantations sampled in this yield study plus five plantations with similar characteristics, and an additional 308 trees from four existing thinning studies.² Sample trees ranged in d.b.h. from 1 to 24 inches (2.5 to 61.0 cm) and in height from 5 to 95 feet (2 to 29 m).

Stem volumes were determined from sets of outside bark diameters and lengths between diameter measurements from a 1-foot (0.3-m) stump to tree top. Diameters were recorded to the nearest 0.1 inch (0.25 cm) and lengths to the nearest 0.1 foot (0.03 m). The number of measurement sets depended upon the size of the tree and locations of rapid form changes. Saplings required, at a minimum, measurement sets at stump, breast height, and total height. Small sawtimber required additional measurements at bases of live crowns and midcrowns. Double bark thickness was estimated to be 0.1765 times the stem diameter (Powers 1969). Trees less than 20 feet (6 m) tall were measured directly with a diameter tape and graduated pole. An optical dendrometer or optical caliper and clinometer were used for measuring taller trees.

Office Procedures

Volume

Stem volumes inside bark in cubic feet were calculated either by Grosenbaugh's (1974) STX computer program or by a similar method using a desk-top computer.

When volumes were plotted over the product of d.b.h. squared and total height (D^2H) (Spurr 1952), differences among volumes of trees planted at different spacings on sites of different productivities could not be found except in one plantation. Trees in this dense, experimental plantation with over 2800 stems per acre (6900 per ha) contained higher volumes for a given D^2H than did trees in more widely spaced plantations. Because this density is higher than that found in practice, these data were not included. One equation was considered adequate for all common site qualities and spacings.

Two weighted, least-squares solutions of the combined-variable formula $V = a + bD^2H$ were computed and compared with the unweighted solution.

Weights tested were $1/D^2H$ and $1/(D^2H)^2$. The weight $1/D^2H$ gave a more precise estimate than either weighting with $1/(D^2H)^2$ or the unweighted solution. Residual error, according to Furnival's (1961) Index of Fit, was reduced substantially. The ratio of the standard error of the unweighted expression to the transformed standard error of the expression weighted by $1/D^2H$ was 2.14. This combined-variable equation of best fit is:

$$V = 0.024843 + 0.0017645 D^2H$$

$$\text{Transformed standard error} = 0.746$$

in which

V = Volume in cubic feet inside bark from 1-foot (0.3-m) stump to tip

Table 2 was constructed using this formula.

Yield

Plantation yields were determined from stem analyses of individual trees by this procedure:

Diameter — Trees were grouped into crown classes. Within each crown class all past and current diameters and heights of each tree and its average linear spacing were fitted by least squares to the expression:

$$\ln Y = a + b \ln X$$

in which

$\ln Y$ = natural logarithm of d.b.h.

$\ln X$ = natural logarithm of the product of linear spacing and height above breast height.

Because we observed many more of the smaller values of the independent variable, the regression coefficients were calculated from the average diameter for each 50 units of the independent variable.

Too few suppressed trees were available to fit the relationship by least squares. Nevertheless, an equation with an intercept constant similar to that of the equation for the intermediate crown class and a slope coefficient 82 percent of that for the dominant crown class seemed to fit the available data well. These equations were obtained and data plotted (fig. 2):

Dominant

$$\ln Y = -1.6107 + 0.6625 \ln X$$

$$S_{y.x} = 0.116$$

$$r = 0.98$$

²Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

Table 2 Volumes for plantation-grown ponderosa pine in cubic feet inside bark from 1-foot stump to tip

D.b.h., o.o. (inches)	5	10	15	20	25	30	35	40	45	50	Total height feet	60	65	70	75	80	85	90	95	100	105	110
1	0.03	0.04	0.05																			
2	0.06	0.10	0.13	0.17	0.20																	
3	0.10	0.18	0.26	0.34	0.42	0.50	0.58															
4		0.31	0.45	0.59	0.73	0.87	1.01	1.15														
5		0.47	0.69	0.91	1.13	1.35	1.57	1.79	2.01	2.23												
6		0.66	0.96	1.30	1.61	1.93	2.25	2.57	2.88	3.20	3.52	3.84										
7		1.32	1.75	2.19	2.62	3.05	3.48	3.92	4.35	4.78	5.21	5.64	6.06	6.51								
8			2.28	2.85	3.41	3.98	4.54	5.11	5.67	6.24	6.80	7.36	7.93	8.49	9.06							
9			2.88	3.60	4.31	5.03	5.74	6.46	7.17	7.89	8.60	9.31	10.03	10.74	11.46	12.17						
10			3.55	4.44	5.32	6.20	7.08	7.97	8.85	9.73	10.61	11.49	12.38	13.26	14.14	15.02	15.91					
11			4.29	5.36	6.43	7.50	8.56	9.63	10.70	11.77	12.84	13.90	14.97	16.04	17.11	18.17	19.24	20.31				
12				6.38	7.65	8.92	10.19	11.46	12.73	14.00	15.27	16.54	17.81	19.08	20.35	21.62	22.89	24.16	25.43			
13				7.48	8.97	10.46	11.95	13.44	14.93	16.43	17.92	19.41	20.90	22.39	23.88	25.37	26.86	28.35	29.84	31.34		
14				8.67	10.40	12.13	13.86	15.59	17.32	19.05	20.78	22.50	24.23	25.96	27.69	29.42	31.15	32.88	34.61	36.34	38.07	
15					11.94	13.92	15.91	17.89	19.88	21.86	23.85	25.83	27.82	29.80	31.79	33.77	35.76	37.74	39.73	41.71	43.70	
16						15.83	18.09	20.35	22.61	24.87	27.13	29.39	31.64	33.90	36.16	38.42	40.68	42.94	45.20	47.45	49.71	
17						17.87	20.42	22.97	25.52	28.07	30.62	33.17	35.72	38.27	40.82	43.37	45.92	48.47	51.02	53.57	56.12	
18						20.03	22.89	25.75	28.61	31.47	34.33	37.18	40.04	42.90	45.76	48.62	51.48	54.34	57.19	60.05	62.91	
19							25.50	28.69	31.87	35.06	38.24	41.43	44.61	47.80	50.98	54.17	57.35	60.54	63.72	66.91	70.09	
20							28.56	31.79	35.31	38.84	42.37	45.90	49.43	52.96	56.49	60.02	63.55	67.08	70.60	74.13	77.66	
21								35.04	38.93	42.82	46.71	50.60	54.49	58.39	62.28	66.17	70.06	73.95	77.84	81.73	85.62	
22								38.46	42.73	47.00	51.27	55.54	59.81	64.08	68.35	72.62	76.89	81.16	85.43	89.70	93.97	
23								46.70	51.36	56.03	60.70	65.36	70.03	74.70	79.37	84.03	88.70	93.37	98.03	102.70	107.37	
24								50.84	55.92	61.01	66.09	71.17	76.25	81.33	86.41	91.50	96.58	101.66	106.74	111.82	116.90	

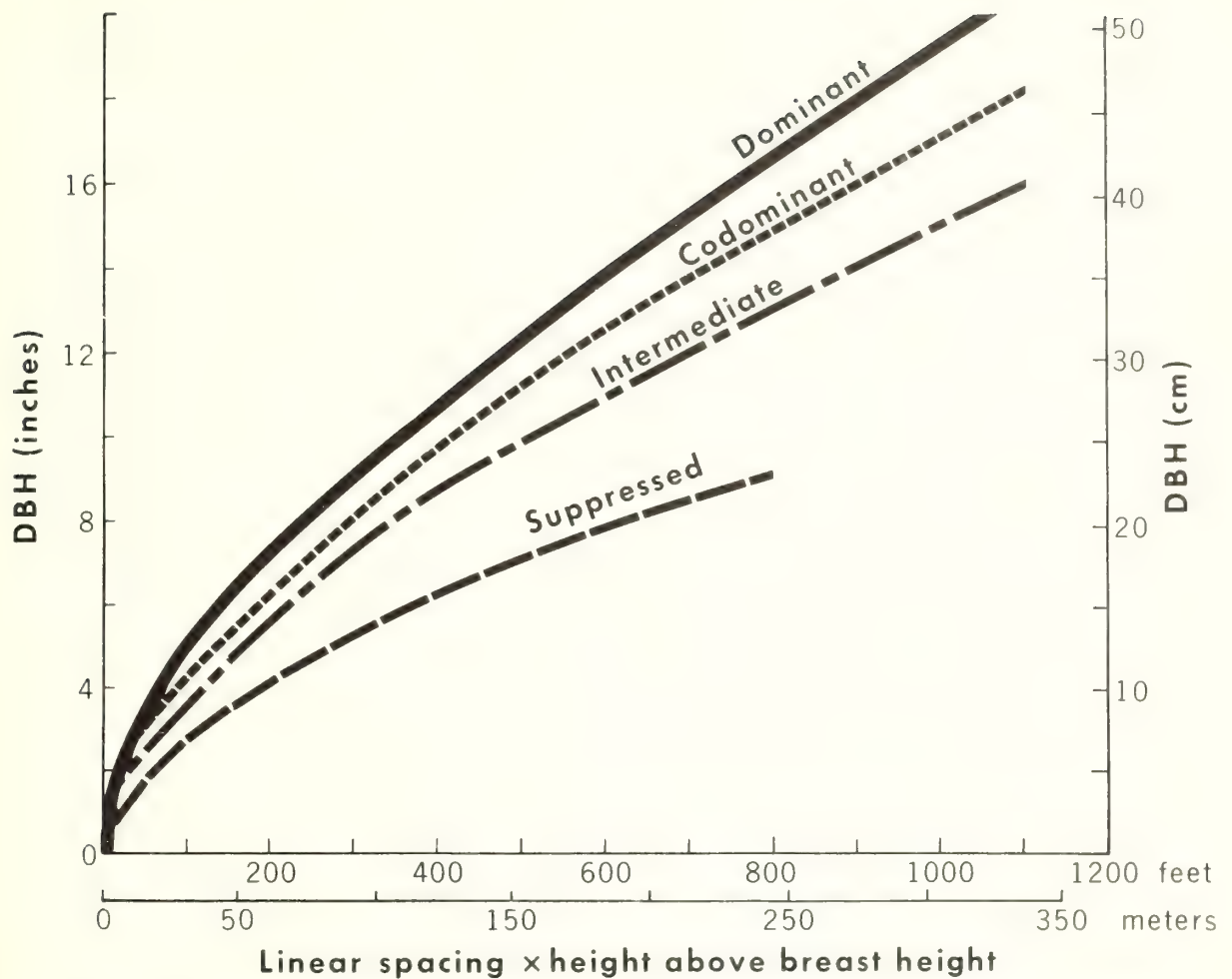


Figure 2—Breast height diameter was related to spacing and height for planted ponderosa pine of four crown classes.

Codominant

$$\ln Y = -1.4217 + 0.6173 \ln X$$

$$S_{y \cdot x} = 0.114$$

$$r = 0.98$$

Intermediate

$$\ln Y = -1.4332 + 0.6008 \ln X$$

$$S_{y \cdot x} = 0.056$$

$$r = 0.97$$

Suppressed

$$\ln Y = -1.4 + 0.54 \ln X$$

Mean heights of codominant and intermediate crown classes were obtained from equations relating their heights to those of dominant trees (Oliver and Powers 1971). Again, because data on suppressed trees were meager, their average heights were estimated to be 40 percent of mean dominant height.

We assumed that height growth is not significantly affected by spacing. Therefore, in constructing this growth model, tree heights for a given crown class, age, and site index are the same regardless of spacing. At extremely high stand densities this is untrue (Oliver 1967). But within the range of densities normally encountered in plantations, it seems to be a reasonable assumption.

The equations relating d.b.h. to spacing and height were combined with site index and heights of subordinate crown classes to construct tables of heights and diameters by age, site index, and crown class (*Appendix, tables 10-14, in part*).

Height — Mean dominant heights for given ages and site indices were taken from recently developed site index curves (Powers and Oliver 1978). These curves for plantations and young natural stands of ponderosa pine in California were derived in part from trees used in this study (*fig. 3*).

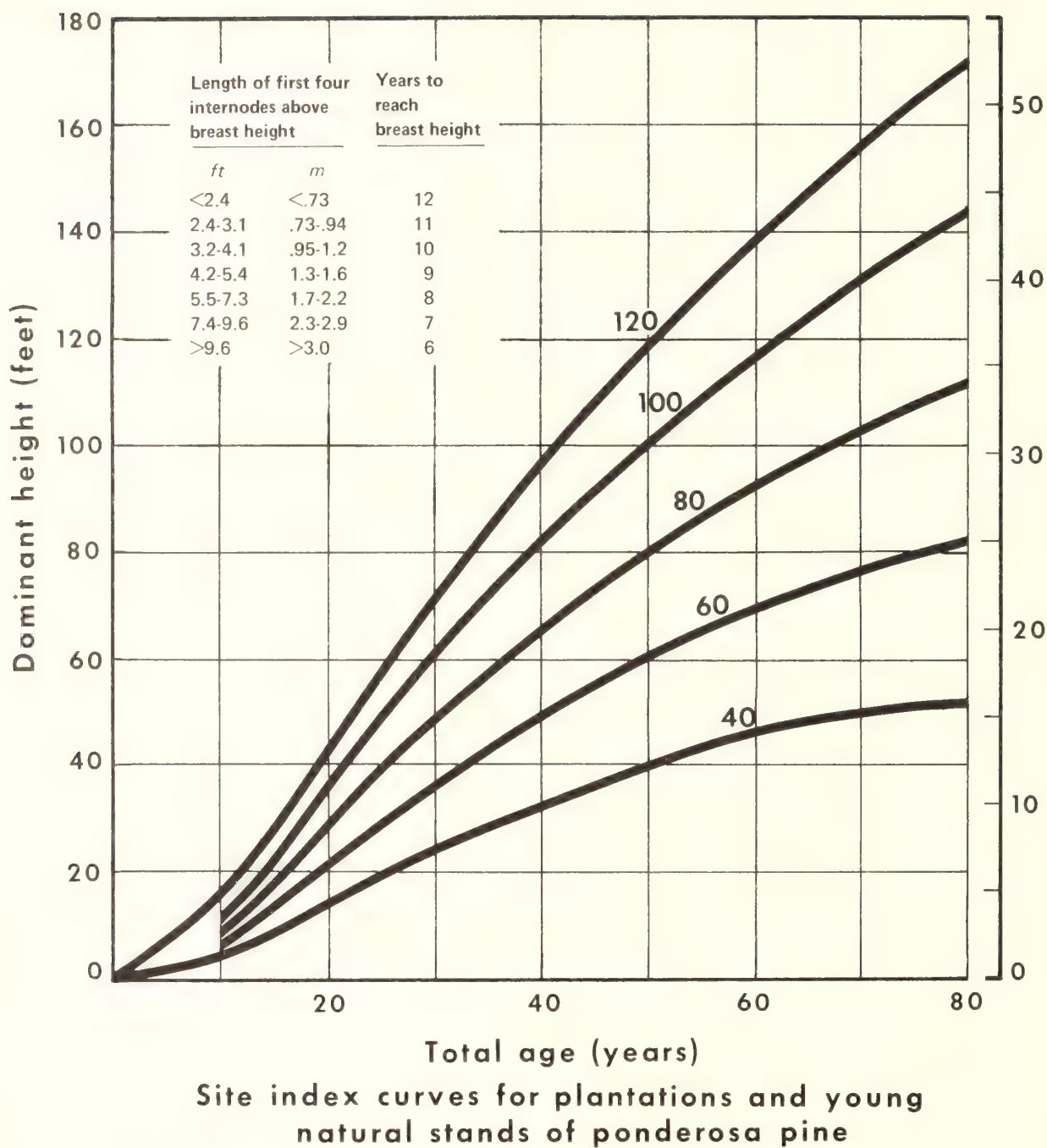


Figure 3—Site index curves for even-aged westside ponderosa pine developed from stem analyses. Adjustment factors are shown for converting breast height age to total age. (From Powers and Oliver 1978)

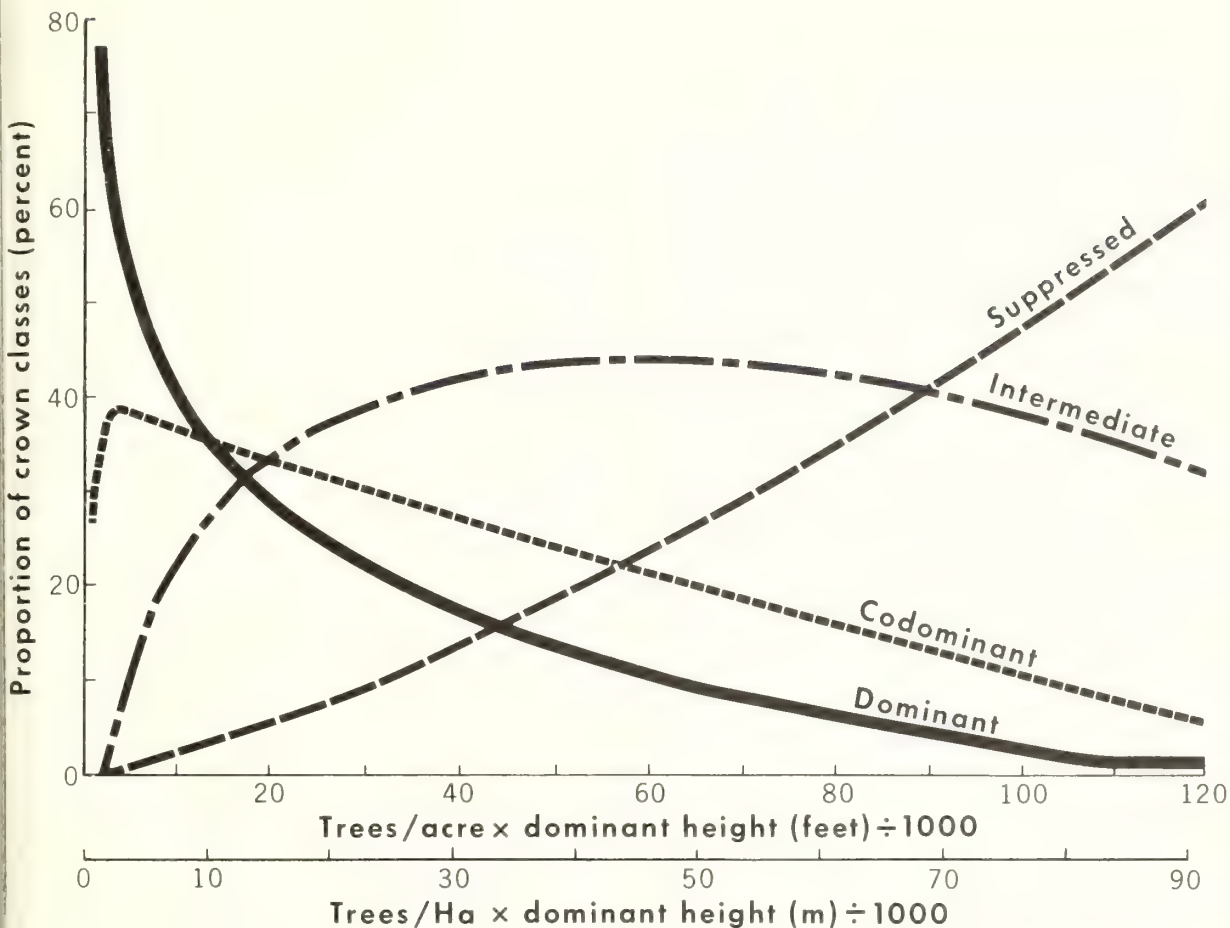


Figure 4—Crown class proportions in unthinned ponderosa pine plantations were related to number of trees per acre and dominant height.

Crown Class — We had the basis for estimating yields from the four crown class components. But, to combine these components into stand yield estimates required information on crown class proportions and mortality, and especially on changes occurring with spacing and time.

We counted the number of trees in each crown class and expressed it as a proportion of total trees in the plantations sampled for stem volume. These data, combined with existing information,³ were plotted over several expressions of spacing times dominant height. The best expression found was trees per acre multiplied by dominant tree height. Correlation coefficients were highly significant for dominant and suppressed crown classes ($r = 0.71$ and 0.74 , respectively), but not significant for codominant crown

classes ($r = 0.29$). No pattern was discernible for intermediate crown classes.

The relationships fitted by least squares were plotted for dominant, codominant, and suppressed classes. Hand adjustment of the curve for dominants was necessary to make it asymptotic at higher values of the independent variable and for codominants to reflect the rapid buildup of this crown class at lower values of the independent variable. The curve for intermediates was constructed from the remainder after subtracting the other three proportions from 100 percent. The resulting curve was biologically valid and fit the plotted data well. Values were read from these plotted relationships (fig. 4) to calculate number of trees per acre for each crown class by spacing and height.

Mortality — We found little evidence of mortality after the initial decline commonly attributed to planting shock. Consequently, we reduced the number of trees

³Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

per acre initially by 15 percent⁴ to account for early mortality and planting skips.

No further reductions in number of trees per acre were calculated until average stand diameter for a given nominal spacing produced a maximum stand density. This maximum density, roughly equivalent to a Stand Density Index of 500 (Reineke 1933), was determined from a survey of dense, natural, even-aged stands in northern California.⁵ It can be expressed by this equation fitted by least squares:

$$\ln N = 10.2687 - 1.7712 \ln D$$

in which

$\ln N$ = natural logarithm of number of trees per acre.

$\ln D$ = natural logarithm of mean stand d.b.h. in inches.

Total number of trees per acre was then reduced for each 5-year period using this relationship.

Crown classes, however, differ in their susceptibility to death from intertree competition. More trees in subordinate crown classes die than do trees in dominant crown classes. Larson (1975), using meager published information, derived this relationship:

⁴Average mortality of successful ponderosa pine plantations in northern California based on our conversations with practicing foresters.

⁵Data on file at Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

$$Y = 0.276 + 0.003 (X-22)^2$$

in which

Y = average annual mortality in percent by d.b.h. for natural stands 10 years after partial cutting
 X = d.b.h. in inches.

Lacking data more appropriate, we applied Larson's mortality data. The resulting percentages were proportioned to total 100 percent and balanced by the numbers of trees in each crown class. Different rates of mortality could then be distributed to each crown class.

Volume Equations — A multivariate equation helped smooth the net cubic volume yields obtained through the model. The following equation form was chosen to reproduce model volumes as closely as possible. We did not attempt to represent the effect of age and site on volume as it occurs in nature and no biological significance should be attributed to the variables or their transformations.

$$\ln Y = \alpha_0 + \alpha_1 A + \alpha_2 S + \alpha_3 A^2 + \alpha_4 S^2 + \alpha_5 A^4 S^2 + \alpha_6 A^2 S + \alpha_7 A S^2$$

in which

$\ln Y$ = natural logarithm of net volume yield in cubic feet,

A = 1/age since planting

S = site index,

α_{0-7} = coefficients which vary by spacing (table 3).

Table 3—Coefficients for the equation relating net cubic volume yield to plantation age and site index depend upon spacing

Spacing (<i>Ft</i>)	Coefficients							
	α_0	α_1	α_2	α_3	α_4	α_5	α_6	α_7
	$X10^0$	$X10^0$	$X10^{-2}$	$X10^0$	$X10^{-4}$	$X10^{-1}$	$X10^0$	$X10^{-3}$
6	7.087370	-114.20401	7.9771886	768.61946	-5.0313026	9.112518	-9.264435	6.634481
8	6.991414	-115.78540	8.1689434	695.84398	-4.7486534	9.841982	-8.059382	5.696333
10	6.850749	-113.62627	8.2534706	599.46115	-4.511247	10.361767	-6.835023	4.846406
12	6.768138	-111.30262	8.1463585	507.31706	-4.1865322	9.570306	-5.409514	3.970905

TESTING THE MODEL'S PREDICTIVE ABILITY

To test our model's predictive ability, we needed real data from new stands. Because of the scarcity of older, well-stocked plantations in California, some of our check data came from 10 of the 12 plantations used in constructing the model. We either measured fixed-area plots in new areas, or in our old areas several years after our first visit. Eight additional plantations were sampled and the files searched for existing data. We found 35 plots suitable for testing the model's predictive ability, though all were not strictly independent of the model.

An evaluation of predicted stand characteristics with observations in ponderosa pine plantations is shown (table 4). The model explained these percentages of variation: 89 percent about the mean diameter, 78 percent about the mean basal area per acre, and 92 percent about the mean cubic volume per acre. Nearly half of the predictions of mean stand diameter were within ± 10 percent of the observations, and only 3 of the 35 were beyond ± 25 percent. Slightly more than half of the time the model overestimated mean stand diameter. But this overestimate averaged less than 0.1 inch (0.25 cm).

Variation between observed and predicted basal area and volume was greater than that for diameter. About one-third of the predicted values were within ± 10 percent of the observed and two-thirds were within $\pm$

25 percent. In contrast to stand diameter, predicted values of basal area and volume were less than observed about two-thirds of the time. Predicted basal area averaged 10 square feet less than observed — a nonsignificant difference. Predicted volume averaged 187 cubic feet less than observed. This difference was statistically significant.

We were disappointed that the model failed to predict stand volumes better. The significant difference between predicted and observed stand volumes, however, may be attributed to the large number of observations in one disjunct plantation. Six of the 35 test plots were from the extensive Sugar Hill Plantation — the only plantation sampled in the Basin and Range Province in northeastern California. Volumes were underestimated for all six plots. When the Sugar Hill plots were excluded, the difference between predicted and observed volumes was not significant, and the number of over- and underestimated volumes was more nearly equal. These yield predictions may be invalid for northeastern California. More likely, however, the Sugar Hill Plantation is uniquely productive, because yields from similar plantations in central Oregon, outside the range of the original data, were not underestimated. Unfortunately, this question must remain unresolved because unthinned plantations of similar age do not exist in northeastern California.

Table 4—Evaluation of observed stand characteristics with those predicted in ponderosa pine plantations in northern California

Stand characteristics	R ²	Observed values in relation to predicted		Observed values less predicted values		t-value for test of 0 difference ¹
		± 10 Pct.	± 25 Pct.	Negative	Positive	
		Percent of plots tested				
Diameter	0.89	46	91	54	43	0.373
Basal area	0.78	34	63	40	57	1.608
Net cubic volume (Sugar Hill Plots included)	0.92	34	71	32	68	2.514
Net cubic volume (Sugar Hill Plots excluded)	0.94	45	79	39	61	1.151

¹ Value of "t" with probability 0.05 and 30 degrees of freedom is 2.042.

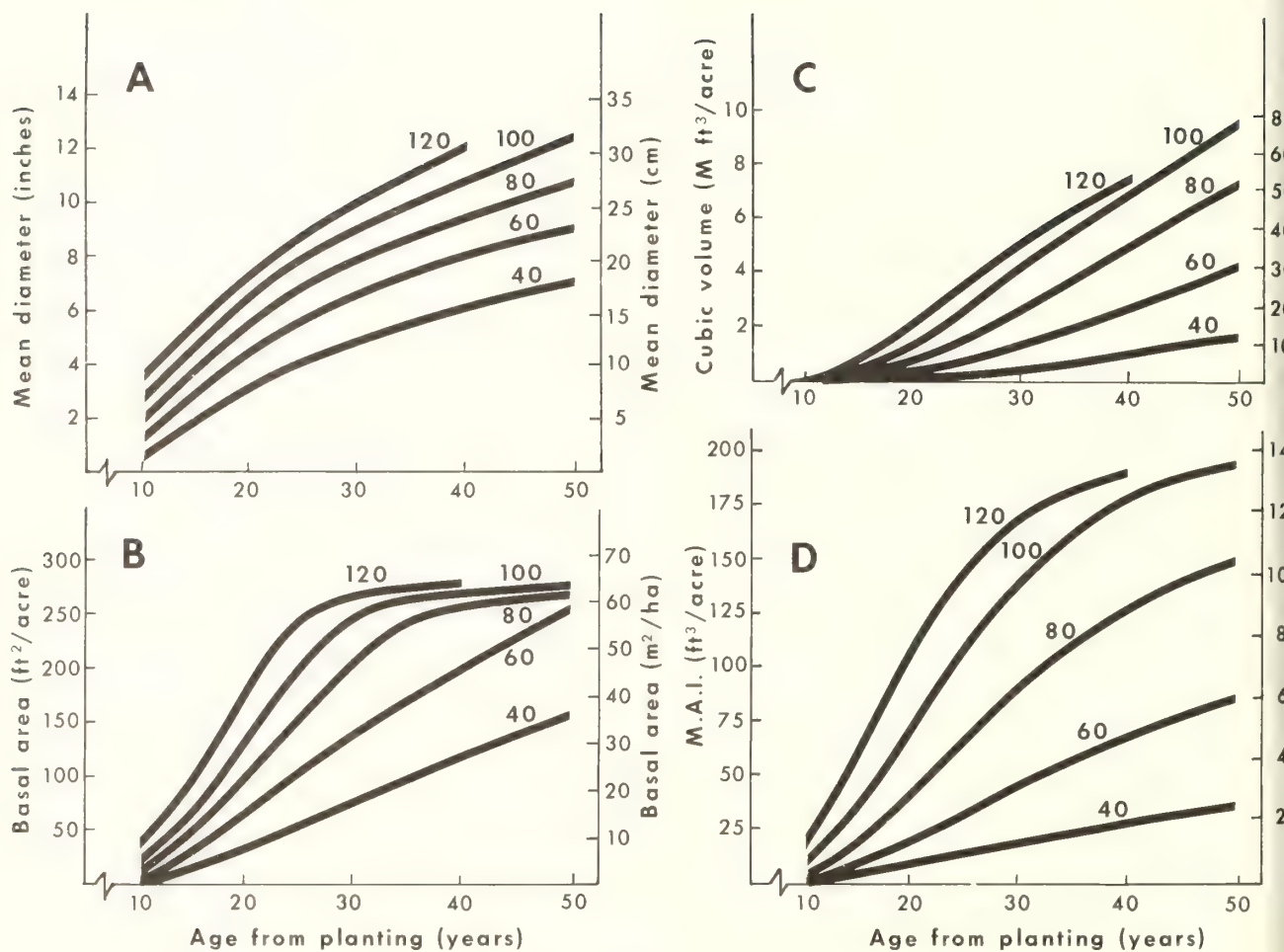


Figure 5—Predicted stand characteristics for ponderosa pine planted at 8 × 8 Site Indices 40 to 120 and ages 10 to 50 years. A. mean stand diameter, B. net basal area, C. net cubic volume, D. mean annual volume increment.

THE YIELD TABLES

The yield tables in this report (*Appendix, tables 5-14*) represent the natural development of high-survival, unthinned ponderosa pine plantations in northern California. Yields are presented first by site indices in increments of 20 feet (6.1 m) from Site Index₅₀ 40 through 120. Within each site index, yields are given every 5 years from 10 to 50 years and for 6-, 8-, 10-, and 12-foot (1.8-, 2.4-, 3.0-, and 3.7-m) spacings (*Appendix, tables 5-9*).

Stand averages are insufficient for making certain management decisions, such as time of earliest commercial thinning. In addition, diameter distributions by crown classes are needed (*Appendix, tables 10-14*).

Some of the relationships (*fig. 5*) are discussed below. For conciseness, only relationships for the 8-foot (2.4-m) spacing are displayed. When spacing effects are discussed, their trends can be verified from the tables.

Mean Stand Diameter

As plantation spacing and site index increase, mean stand diameter increases. In general, diameter increases with age, also. But for 6-foot (1.8-m) spacings at Site Index 120 (37 m) growth is negligible above age 35 (*Appendix, table 9*), indicating growth stagnation caused by high stand density. Periodic annual increment in diameter culminates at 10 years or less for all spacings and site indices.

Basal Area

Basal area increase is nearly linear with age for Site Indices 60 and below, but becomes increasingly curvilinear above Site Index 60. By 30 years net basal area accumulated on Site Indices 100 and 120 are similar and have nearly reached their maximum of about 280 square feet per acre (64 m²/ha). Maximum basal area accumulated by 40 years on Site Index 80 but required more than 50 years on poorer sites. Basal area differences among spacings are small compared with those differences among site indices and age.

Cubic Volume

With increasing age and site index, net cubic volume increases nearly linearly. Similar to basal area, volume differences among spacings are less than those among ages and site indices. Only at older ages on better sites are volume differences among spacings large. The model predicts less volume as spacing becomes closer (*Appendix, tables 5-9*), suggesting volume growth stagnation beyond 30 years on Site Indices 80 and better. Periodic annual increment culminates at older ages for plantations spaced wider and at younger ages for plantations on better sites.

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APPENDIX

Table 5.

Yields of unthinned ponderosa pine plantations in northern California (Site Index)

Age from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft ²)	Total net volume/ac (ft ³)
10	6 x 6	1028	4	0.4	1	26
	8 x 8	579	5	0.5	1	15
	10 x 10	370	5	0.6	1	10
	12 x 12	257	5	0.7	1	7
15	6 x 6	1028	8	1.5	13	79
	8 x 8	579	8	1.9	12	59
	10 x 10	370	8	2.2	10	47
	12 x 12	257	8	2.6	9	40
20	6 x 6	1028	12	2.6	37	200
	8 x 8	579	13	3.2	32	166
	10 x 10	370	13	3.8	30	143
	12 x 12	257	13	4.4	27	127
25	6 x 6	1028	17	3.4	64	392
	8 x 8	579	17	4.2	57	342
	10 x 10	370	18	5.0	51	305
	12 x 12	257	18	5.8	47	278
30	6 x 6	1028	21	4.0	88	642
	8 x 8	579	22	5.0	78	578
	10 x 10	370	22	6.0	72	526
	12 x 12	257	23	6.8	67	485
35	6 x 6	1028	24	4.5	112	934
	8 x 8	579	25	5.7	101	860
	10 x 10	370	26	6.7	91	791
	12 x 12	257	26	7.7	84	733
40	6 x 6	1028	27	4.9	135	1252
	8 x 8	579	29	6.2	120	1172
	10 x 10	370	29	7.4	110	1084
	12 x 12	257	30	8.5	100	1008
45	6 x 6	1028	30	5.2	153	1585
	8 x 8	579	32	6.7	141	1500
	10 x 10	370	33	7.9	127	1393
	12 x 12	257	33	9.1	116	1298
50	6 x 6	1028	32	5.5	172	1922
	8 x 8	579	35	7.1	158	1836
	10 x 10	370	36	8.4	143	1709
	12 x 12	257	36	9.7	132	1595

Table 6.
Yields of unthinned ponderosa pine plantations in northern California (Site Index 60)

Age from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft ²)	Total net volume/acre (ft ³)
10	6 x 6	1028	6	0.8	4	33
	8 x 8	579	6	1.1	4	23
	10 x 10	370	6	1.4	4	17
	12 x 12	257	6	1.6	5	14
15	6 x 6	1028	11	2.3	29	156
	8 x 8	579	12	2.9	26	127
	10 x 10	370	12	3.4	24	108
	12 x 12	257	12	3.9	22	96
20	6 x 6	1028	18	3.6	74	445
	8 x 8	579	19	4.5	65	392
	10 x 10	370	19	5.4	59	353
	12 x 12	257	20	6.1	53	323
25	6 x 6	1028	24	4.5	116	896
	8 x 8	579	26	5.7	103	830
	10 x 10	370	26	6.8	94	768
	12 x 12	257	27	7.8	86	713
30	6 x 6	1028	30	5.2	153	1469
	8 x 8	579	32	6.7	141	1405
	10 x 10	370	33	7.9	127	1323
	12 x 12	257	33	9.1	116	1240
35	6 x 6	1028	35	5.8	187	2117
	8 x 8	579	37	7.4	174	2073
	10 x 10	370	38	8.9	158	1974
	12 x 12	257	39	10.2	147	1861
40	6 x 6	1028	39	6.2	214	2804
	8 x 8	579	42	8.0	203	2794
	10 x 10	370	43	9.6	187	2681
	12 x 12	257	44	11.1	172	2538
45	6 x 6	1028	42	6.5	240	3502
	8 x 8	579	46	8.6	232	3539
	10 x 10	370	48	10.3	214	3415
	12 x 12	257	49	11.9	199	3243
50	6 x 6	966	45	6.8	246	4195
	8 x 8	579	50	9.0	258	4286
	10 x 10	370	52	10.9	240	4153
	12 x 12	257	54	12.6	223	3953

Table 7.

Yields of unthinned ponderosa pine plantations in northern California (Site Index

Age from planting (inches)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft ²)	Total n volume/a (ft ³)
10	6 x 6	1028	8	1.5	12	51
	8 x 8	579	8	1.9	11	40
	10 x 10	370	8	2.2	10	33
	12 x 12	257	8	2.6	9	29
15	6 x 6	1028	15	3.1	53	300
	8 x 8	579	16	3.9	48	257
	10 x 10	370	16	4.5	41	227
	12 x 12	257	16	5.2	38	207
20	6 x 6	1028	24	4.5	112	869
	8 x 8	579	25	5.6	100	803
	10 x 10	370	26	6.6	89	742
	12 x 12	257	26	7.7	82	690
25	6 x 6	1028	32	5.4	165	1700
	8 x 8	579	34	7.0	154	1656
	10 x 10	370	35	8.3	139	1577
	12 x 12	257	36	9.5	128	1488
30	6 x 6	1028	38	6.2	214	2685
	8 x 8	579	42	8.0	204	2718
	10 x 10	370	43	9.6	185	2642
	12 x 12	257	44	11.1	171	2523
35	6 x 6	991	44	6.7	241	3735
	8 x 8	579	48	8.8	245	3892
	10 x 10	370	50	10.6	227	3841
	12 x 12	257	52	12.3	211	3703
40	6 x 6	894	49	7.1	248	4793
	8 x 8	525	55	9.6	261	5108
	10 x 10	370	57	11.5	266	5098
	12 x 12	257	59	13.3	249	4952
45	6 x 6	812	53	7.5	250	5824
	8 x 8	471	61	10.2	265	6319
	10 x 10	339	63	12.3	280	6363
	12 x 12	257	65	14.2	282	6220
50	6 x 6	757	57	7.8	252	6810
	8 x 8	426	66	10.8	269	7497
	10 x 10	307	69	13.0	284	7603
	12 x 12	233	71	15.1	291	7472

le 8.

lds of unthinned ponderosa pine plantations in northern California (Site Index 100)

from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft ²)	Total net volume/acre (ft ³)
10	6 x 6	1028	10	2.0	23	98
	8 x 8	579	10	2.6	21	82
	10 x 10	370	10	3.0	18	72
	12 x 12	257	11	3.5	17	66
15	6 x 6	1028	18	3.6	72	556
	8 x 8	579	19	4.0	63	490
	10 x 10	370	19	5.4	58	437
	12 x 12	257	20	6.1	53	401
20	6 x 6	1028	29	5.2	151	1484
	8 x 8	579	31	6.6	136	1418
	10 x 10	370	32	7.8	123	1325
	12 x 12	257	33	9.0	113	1241
25	6 x 6	1028	38	6.2	214	2670
	8 x 8	579	42	8.0	203	2719
	10 x 10	370	43	9.6	185	2640
	12 x 12	257	44	11.1	172	2527
30	6 x 6	942	46	6.9	246	3920
	8 x 8	570	51	9.1	258	4191
	10 x 10	370	53	11.0	244	4189
	12 x 12	257	54	12.7	226	4089
35	6 x 6	812	53	7.5	247	5131
	8 x 8	484	60	10.0	266	5697
	10 x 10	343	62	12.2	278	5823
	12 x 12	257	64	14.1	279	5775
40	6 x 6	758	58	7.8	255	6259
	8 x 8	419	68	10.9	271	7159
	10 x 10	298	71	13.2	285	7446
	12 x 12	227	73	15.4	292	7486
45	6 x 6	709	62	8.1	254	7288
	8 x 8	375	75	11.6	277	8540
	10 x 10	259	80	14.3	290	9009
	12 x 12	203	81	16.4	299	9161
50	6 x 6	679	66	8.3	255	8221
	8 x 8	329	83	12.5	279	9826
	10 x 10	225	90	15.5	295	10486
	12 x 12	185	89	17.2	301	10766

Table 9.

Yields of unthinned ponderosa pine plantations in northern California (Site Index)

Age from planting (years)	Planted spacing (ft)	Trees per acre	Mean height (ft)	Mean d.b.h. (inches)	Basal area/acre (ft ²)	Total r volume/acre (ft ³)
10	6 x 6	1028	13	2.8	42	228
	8 x 8	579	14	3.5	38	197
	10 x 10	370	14	4.1	34	174
	12 x 12	257	14	4.7	31	158
15	6 x 6	1028	23	4.3	106	997
	8 x 8	579	24	5.4	94	880
	10 x 10	370	25	6.5	84	773
	12 x 12	257	25	7.4	77	699
20	6 x 6	1028	34	5.7	184	2221
	8 x 8	579	37	7.4	172	2161
	10 x 10	370	38	8.8	158	2015
	12 x 12	257	39	10.2	145	1883
25	6 x 6	966	45	6.8	240	3473
	8 x 8	579	49	8.9	250	3670
	10 x 10	370	51	10.7	232	3605
	12 x 12	257	53	12.4	216	3494
30	6 x 6	812	53	7.5	250	4572
	8 x 8	471	61	10.2	266	5151
	10 x 10	336	63	12.3	277	5274
	12 x 12	257	65	14.2	282	5274
35	6 x 6	725	60	8.0	254	5487
	8 x 8	393	71	11.2	271	6500
	10 x 10	278	75	13.7	286	6877
	12 x 12	215	77	15.9	296	7060
40	6 x 6	694	65	8.1	251	6241
	8 x 8	343	81	12.2	279	7693
	10 x 10	235	86	15.1	291	8355
	12 x 12	185	88	17.3	303	8768

Table 10. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 40)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is				Trees per acre when crown class is			
		D	C	I	S	D	C	I	S
		inches				number			
10	6 x 6	0.5	0.0	0.0	0.0	519	390	114	5
	8 x 8	0.6	0.0	0.0	0.0	342	220	16	1
	10 x 10	0.7	0.0	0.0	0.0	240	129	1	0
	12 x 12	0.8	0.0	0.0	0.0	180	77	0	0
15	6 x 6	1.8	1.4	1.0	0.0	428	388	196	16
	8 x 8	2.2	1.7	1.1	0.0	294	220	61	4
	10 x 10	2.5	1.9	1.3	0.0	215	140	14	1
	12 x 12	2.8	2.2	1.5	0.0	162	91	4	0
20	6 x 6	3.0	2.6	2.1	0.7	350	355	290	33
	8 x 8	3.6	3.1	2.5	0.8	250	214	106	9
	10 x 10	4.2	3.6	2.8	0.9	189	141	38	2
	12 x 12	4.7	4.0	3.2	1.0	145	98	13	1
25	6 x 6	4.0	3.5	2.9	1.2	292	339	344	53
	8 x 8	4.8	4.2	3.5	1.4	220	208	137	14
	10 x 10	5.6	4.8	4.0	1.6	160	139	67	4
	12 x 12	6.3	5.4	4.4	1.8	131	98	26	2
30	6 x 6	4.7	4.2	3.5	1.6	257	325	374	72
	8 x 8	5.7	5.0	4.2	1.9	198	203	160	18
	10 x 10	6.7	5.8	4.8	2.1	152	136	75	7
	12 x 12	7.5	6.5	5.4	2.3	123	97	35	2
35	6 x 6	5.4	4.8	4.0	1.9	231	310	397	90
	8 x 8	6.6	5.7	4.8	2.2	182	197	177	23
	10 x 10	7.6	6.6	5.5	2.4	144	130	87	9
	12 x 12	8.6	7.4	6.1	2.7	116	96	41	4
40	6 x 6	6.0	5.3	4.5	2.1	211	295	413	109
	8 x 8	7.2	6.3	5.3	2.4	170	194	187	28
	10 x 10	8.4	7.3	6.1	2.7	137	132	91	10
	12 x 12	9.5	8.1	6.8	3.0	110	95	48	4
45	6 x 6	6.5	5.8	4.8	2.3	189	284	428	127
	8 x 8	7.9	6.9	5.8	2.6	161	190	196	32
	10 x 10	9.1	7.9	6.6	3.0	129	131	99	11
	12 x 12	10.3	8.8	7.3	3.3	106	94	52	5
50	6 x 6	7.0	6.2	5.2	2.4	173	274	435	146
	8 x 8	8.4	7.4	6.2	2.8	152	185	206	36
	10 x 10	9.8	8.4	7.0	3.2	124	129	105	12
	12 x 12	11.0	9.4	7.9	3.5	102	94	50	5

Table 11. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 60)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is				Trees per acre when crown class is			
		D	C	I	S	D	C	I	S
		inches				number			
10	6 x 6	1.1	0.6	0.0	0.0	447	380	186	15
	8 x 8	1.4	0.8	0.0	0.0	309	223	44	5
	10 x 10	1.6	0.9	0.0	0.0	223	139	8	0
	12 x 12	1.8	1.0	0.0	0.0	166	91	0	0
15	6 x 6	2.7	2.3	1.8	0.5	350	360	287	31
	8 x 8	3.2	2.8	2.2	0.6	255	215	101	8
	10 x 10	3.8	3.2	2.5	0.7	190	141	36	3
	12 x 12	4.2	3.6	2.8	0.8	146	98	12	1
20	6 x 6	4.3	3.8	3.1	1.4	278	333	357	60
	8 x 8	5.2	4.5	3.7	1.6	210	206	147	16
	10 x 10	6.0	5.2	4.3	1.8	161	137	66	6
	12 x 12	6.7	5.8	4.8	2.0	126	98	31	2
25	6 x 6	5.5	4.9	4.1	1.9	223	306	401	98
	8 x 8	6.6	5.8	4.9	2.2	179	197	179	24
	10 x 10	7.7	6.8	5.6	2.5	142	133	87	8
	12 x 12	8.7	7.5	6.2	2.7	114	96	44	3
30	6 x 6	6.5	5.8	4.8	2.3	190	286	426	126
	8 x 8	7.9	6.9	5.8	2.6	161	190	196	32
	10 x 10	9.1	7.9	6.6	3.0	129	130	100	11
	12 x 12	10.3	8.8	7.3	3.3	105	94	53	5
35	6 x 6	7.4	6.5	5.5	2.6	159	265	442	162
	8 x 8	8.9	7.8	6.5	3.0	145	182	211	41
	10 x 10	10.4	8.9	7.4	3.4	118	127	111	14
	12 x 12	11.7	10.0	8.3	3.7	98	93	60	6
40	6 x 6	8.1	7.1	6.0	2.8	138	247	449	194
	8 x 8	9.8	8.5	7.1	3.3	133	176	221	49
	10 x 10	11.4	9.8	8.1	3.7	111	125	117	17
	12 x 12	12.8	10.9	9.1	4.1	92	91	67	7
45	6 x 6	8.8	7.7	6.5	3.0	118	228	456	226
	8 x 8	10.6	9.2	7.7	3.5	123	171	229	56
	10 x 10	12.3	10.5	8.8	4.0	104	122	125	19
	12 x 12	13.9	11.8	9.8	4.4	88	90	71	8
50	6 x 6	9.4	8.2	6.9	3.2	99	201	429	237
	8 x 8	11.3	9.8	8.2	3.8	115	166	234	61
	10 x 10	13.1	11.2	9.4	4.3	100	120	128	22
	12 x 12	14.8	12.6	10.4	4.7	84	89	75	9

Table 12. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 80)

from thinning (years)	Planted spacing (ft)	Mean d.b.h. when crown class is				Trees per acre when crown class is			
		D	C	I	S	D	C	I	S
		inches				number			
0	6 x 6	1.8	1.4	1.0	0.0	397	370	238	23
	8 x 8	2.2	1.7	1.2	0.0	278	219	76	6
	10 x 10	2.5	1.9	1.4	0.0	206	142	21	1
	12 x 12	2.8	2.2	1.5	0.0	154	97	6	0
5	6 x 6	3.6	3.2	2.6	1.1	305	346	330	47
	8 x 8	4.4	3.9	3.1	1.2	226	210	131	12
	10 x 10	5.0	4.3	3.6	1.4	168	139	59	4
	12 x 12	5.7	4.9	4.0	1.5	133	98	24	2
10	6 x 6	5.4	4.8	4.0	1.8	233	311	394	90
	8 x 8	6.5	5.7	4.8	2.2	182	198	176	23
	10 x 10	7.5	6.5	5.4	2.4	144	134	84	8
	12 x 12	8.5	7.3	6.1	2.7	116	96	42	3
15	6 x 6	6.8	6.0	5.1	2.4	178	277	433	140
	8 x 8	8.3	7.2	6.1	2.8	155	186	203	35
	10 x 10	9.6	8.3	6.9	3.1	125	129	104	12
	12 x 12	10.8	9.3	7.7	3.5	102	94	56	5
20	6 x 6	8.1	7.1	6.0	2.8	139	247	449	193
	8 x 8	9.8	8.5	7.1	3.3	134	177	221	47
	10 x 10	11.3	9.7	8.1	3.7	111	125	117	17
	12 x 12	12.8	10.9	9.0	4.1	92	91	67	7
25	6 x 6	9.1	7.9	6.7	3.1	108	214	440	229
	8 x 8	11.0	9.5	7.9	3.7	119	168	232	60
	10 x 10	12.7	10.9	9.1	4.1	102	121	126	21
	12 x 12	14.4	12.2	10.1	4.6	85	89	75	8
30	6 x 6	10.0	8.7	7.3	3.4	81	175	399	239
	8 x 8	12.1	10.4	8.7	4.0	100	147	217	61
	10 x 10	14.0	11.9	9.9	4.5	95	118	132	25
	12 x 12	15.8	13.3	11.1	5.0	81	88	78	10
35	6 x 6	10.8	9.3	7.9	3.7	61	147	363	241
	8 x 8	13.0	11.2	9.3	4.3	84	128	200	59
	10 x 10	15.1	12.8	10.7	4.8	83	106	126	24
	12 x 12	17.0	14.3	11.9	5.3	76	86	83	12
40	6 x 6	11.5	9.9	8.4	3.9	49	124	336	248
	8 x 8	13.9	11.9	9.9	4.5	71	115	186	54
	10 x 10	16.1	13.6	11.3	5.1	74	95	116	22
	12 x 12	18.2	15.2	12.7	5.6	68	78	78	9

Table 13. Mean diameters and number of trees by crown classes for unthinned ponderosa pine plantations in northern California (Site Index 100)

Age from planting (years)	Planted spacing (ft)	Mean d.b.h. when crown class is				Trees per acre when crown class is			
		D	C	I	S	D	C	I	
		inches				number			
10	6 x 6	2.4	2.0	1.6	0.2	358	361	277	
	8 x 8	2.9	2.4	1.9	0.2	259	215	97	
	10 x 10	3.3	2.8	2.1	0.2	190	141	36	
	12 x 12	3.8	3.1	2.4	0.2	148	98	11	
15	6 x 6	4.2	3.8	3.1	1.4	268	330	365	
	8 x 8	5.1	4.5	3.7	1.6	204	204	154	
	10 x 10	6.0	5.2	4.3	1.8	157	136	71	
	12 x 12	6.7	5.8	4.7	2.0	126	97	32	
20	6 x 6	6.4	5.7	4.8	2.2	195	288	423	1
	8 x 8	7.7	6.8	5.7	2.6	162	190	196	
	10 x 10	9.0	7.7	6.5	2.9	130	130	99	
	12 x 12	10.1	8.7	7.2	3.2	107	95	50	
25	6 x 6	8.1	7.1	6.0	2.8	139	247	450	1
	8 x 8	9.8	8.5	7.1	3.3	134	177	220	
	10 x 10	11.3	9.7	8.1	3.7	111	125	117	
	12 x 12	12.8	10.9	9.1	4.1	93	91	66	
30	6 x 6	9.5	8.3	7.0	3.3	96	196	417	2
	8 x 8	11.4	9.9	8.3	3.8	112	162	233	
	10 x 10	13.3	11.3	9.5	4.3	98	120	130	
	12 x 12	15.0	12.7	10.5	4.7	83	89	75	
35	6 x 6	10.7	9.3	7.8	3.6	63	150	363	2
	8 x 8	12.9	11.0	9.2	4.2	86	133	205	
	10 x 10	14.9	12.7	10.6	4.8	84	108	127	
	12 x 12	16.9	14.2	11.8	5.3	77	87	81	
40	6 x 6	11.7	10.1	8.5	3.9	46	119	337	2
	8 x 8	14.1	12.0	10.1	4.6	70	110	185	
	10 x 10	16.4	13.8	11.5	5.2	70	93	114	
	12 x 12	18.5	15.5	12.8	5.7	67	73	78	
45	6 x 6	12.6	10.8	9.1	4.2	33	95	307	2
	8 x 8	15.2	13.0	10.8	4.9	56	99	171	
	10 x 10	17.7	14.9	12.5	5.6	60	81	102	
	12 x 12	19.9	16.6	13.8	6.1	58	62	76	
50	6 x 6	13.4	11.5	9.7	4.4	19	79	289	2
	8 x 8	16.2	13.8	11.5	5.2	49	88	156	
	10 x 10	18.8	15.8	13.1	5.9	55	73	96	
	12 x 12	21.2	17.7	14.6	6.5	50	52	76	

le 14. Mean diameters and number of trees by crown classes for unthinned
derosa pine plantations in northern California (Site Index 120)

from nting ars)	Planted spacing (ft)	Mean d.b.h. when crown class is				Trees per acre when crown class is			
		D	C	I	S	D	C	I	S
		inches				number			
0	6 x 6	3.2	2.8	2.3	0.9	329	354	306	39
	8 x 8	3.9	3.4	2.7	1.0	241	212	116	10
	10 x 10	4.5	3.9	3.1	1.1	181	140	46	3
	12 x 12	5.1	4.3	3.5	1.3	140	98	18	1
5	6 x 6	5.2	4.6	3.9	1.8	241	315	388	84
	8 x 8	6.3	5.5	4.6	2.1	188	200	170	21
	10 x 10	7.3	6.3	5.2	2.3	148	135	80	7
	12 x 12	8.2	7.1	5.8	2.6	117	96	41	3
0	6 x 6	7.3	6.5	5.4	2.5	162	275	431	160
	8 x 8	8.9	7.7	6.5	3.0	146	183	209	41
	10 x 10	10.3	8.9	7.4	3.4	120	128	108	14
	12 x 12	11.6	9.9	8.3	3.7	99	93	59	6
5	6 x 6	9.2	8.0	6.8	3.2	103	207	428	228
	8 x 8	11.1	9.6	8.1	3.7	117	167	232	63
	10 x 10	12.9	11.0	9.2	4.2	101	121	127	21
	12 x 12	14.6	12.3	10.3	4.6	85	89	74	9
0	6 x 6	10.8	9.3	7.9	3.7	61	147	363	241
	8 x 8	13.0	11.2	9.3	4.3	86	129	197	59
	10 x 10	15.1	12.8	10.7	4.8	82	105	125	24
	12 x 12	17.0	14.3	11.9	5.3	76	86	83	12
5	6 x 6	12.1	10.5	8.8	4.1	37	110	317	261
	8 x 8	14.6	12.5	10.4	4.8	63	103	175	52
	10 x 10	17.0	14.3	11.9	5.4	66	86	107	19
	12 x 12	19.2	16.0	13.3	5.9	63	67	77	8
0	6 x 6	13.2	11.4	9.5	4.4	21	80	290	303
	8 x 8	16.0	13.6	11.3	5.2	51	90	158	44
	10 x 10	18.6	15.6	13.0	5.8	54	74	96	11
	12 x 12	21.0	17.5	14.5	6.4	51	62	66	6



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Oliver, William W., and Robert F. Powers.

1978. **Growth models for ponderosa pine: I. Yield of unthinned plantations in northern California.** Res. Paper PSW-133, 21 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

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Oxford: 174.7 *Pinus ponderosa* — 566(+612)

Retrieval Terms: *Pinus ponderosa*; plantations; growth models; yield tables; basal area; volume; northern California.

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Control of Brush Regrowth with Herbicides in Pine Plantations in Northern California

Jay R. Bentley Kenneth M. Estes



The Authors

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CONTENTS

	<i>Page</i>
Introduction	1
Study Area and Procedures	1
Herbicide Treatments	2
Brush Plant Records	2
Patterns of Brush Regrowth	4
Shrub Species, Foresthill	4
Shrub Species, Viola and Mount Shasta	4
Control of Brush Regrowth by Treatment	5
Single Herbicide Application	5
Repeated Herbicide Applications	5
Hand Sprays vs. Broadcast Sprays	6
Different Herbicides	7
Different Broadcast Dosage Rates	8
Discussion	9
Conclusions	11
Plant Susceptibility to Herbicides	11
Spacing of Herbicide Applications	11
Selection of Herbicide	12
Herbicide Dosage Rates	12
Herbicide Application Method	13
Literature Cited	13

IN BRIEF...

Bentley, Jay R., and Kenneth M. Estes.

1978. **Control of brush regrowth with herbicides on pine plantations in northern California.** Res. Paper PSW-134, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Oxford: 441—441.1:176. 1 *Arctostaphylos* spp. +232.214:176.1 *Arctostaphylos*

Retrieval Terms: Brush control; manzanita; herbicides; site preparation; plantations; ponderosa pine.

Comprehensive tests of herbicides for controlling regrowth of brush were made on land cleared for pine plantations in northern California. Treatments were applied during 1962-65 on burned-over forest and on two bulldozed brushfields. A tractor-drawn sprayer equipped with a boom and hoses was used to simulate practical operations on 324 large plots covering 64.8 acres. Broadcast sprays or hand applications on individual plants, or both, were made once, twice, or three times in consecutive years, beginning in 1962, in nine combinations of method and year. Three herbicides—2,4-D [(2,4-dichlorophenoxy) acetic acid], 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid], and a 1:1 mixture of the two—were tested at three dosage levels. The herbicides were applied during the summer when conditions were favorable for brush kill. Results from these tests were supported in subsequent years by observations of larger areas sprayed by helicopter during both summer and fall months.

Susceptibility of brush regrowth to herbicides depended more on size and density of plant crown and on development of root systems than on species of shrub. First-year seedlings and sprouting plants with small open crowns were commonly killed by a single application. Repeated sprays were required to kill vigorous plants that had developed large, dense crowns before the initial herbicide application. Two sprays in consecutive years greatly reduced vigor and competitive effect of most brush stands, but many living plants were still present. Three sprays produced excellent control of the most resistant plants on the plots and killed the numerous small seedlings which became established on bulldozed areas during 1963 and 1964.

Experience in applying results from test plots showed that spray treatments started during the first or second year after land clearing, and repeated as needed, produced consistent brush control with minimum use of herbicides. However, when the initial application was delayed a few years until the brush regrowth had become well established, results were more erratic and heavier dosages and more follow-up applications were required, with consequently less ef-

ficient use of herbicides and money. Repeated spraying in consecutive years or alternate years provide much more effective use of herbicides than did wide spacing of repeated applications. Land use objective will determine the number of repeat application needed in each situation.

Each herbicide—2,4-D, 2,4,5-T, or a 1:1 mixture of the two—produced satisfactory brush kill on the test plots. For site preparation spraying, 2,4-D alone or combined with 2,4,5-T usually is used to control brush reestablishment ahead of pine planting. For release spraying over planted pines, the usual practice is to apply 2,4,5-T alone because of the greater tolerance of ponderosa pine (*Pinus ponderosa* Laws.) to this herbicide. This herbicide controls most brush species, but is relatively ineffective on mariposa manzanita (*Arctostaphylos mariposa* Dudl.).

An herbicide dosage of 3 to 4 pounds, a.e., per acre was most effective and economical in most situations. A 2-pound dosage was effective on first-year brush seedlings, and it killed resistant plants on plots sprayed in 3 consecutive years; but this low dosage was ineffective where applied on well-established brush regrowth or where a single spray was applied. A 4-pound rate produced consistently good brush control in repeated applications; it was particularly needed if the initial spray was delayed past the first year of brush regrowth or when repeat spraying occurred in alternate years or at longer intervals. An 8-pound rate produced greatest kill from a single application but was in excess of need for repeat applications. A total of 8 to 10 pounds, a.e. of herbicide per acre spread over two or three applications would be much more effective and efficient.

Hand spraying effectively controlled the more vigorous brush regrowth but many recently germinated small seedlings always were missed. Consequently broadcast spraying produced better control of the total brush stand; it is a much faster and cheaper application for use on large areas. Hand spraying may be needed under special conditions when broadcast sprays are not possible or are inadvisable.

Forest managers in California have long been aware of the need for controlling brush regrowth on cleared land. Before 1962, however, the research on use of herbicides to control our mountain brush species was inadequate for the development of techniques practical on large areas. The earlier work had been limited mainly to tests of hand applications of chemicals on individual brush plants. Though effective, this method was too time consuming and costly for wide-scale use.

During the period 1962-65, comprehensive tests of repeated herbicide applications were conducted on large plots in northern California. The aim was to develop quickly some practical methods for using herbicides to control brush on thousands of acres being planted to pine. Results of this administrative study, conducted jointly by the California Region and the Pacific Southwest Forest and Range Experiment Station of the U.S. Forest Service, were applied, as they became apparent year by year, in the form of guidelines prepared for large-scale spraying projects. Also, an instructional manual was written at the end of the study (Bentley and Estes 1965), and a brief summary of the effectiveness of repeated herbicide applications was issued (Bentley 1967). The present report documents the comprehensive study and includes previously unpublished data.

The approach taken in these tests of herbicide application emphasized the development of practical

methods for wide-scale use. We compared hand applications with broadcast boom methods, which showed greater promise. We tested the two application methods as single treatments and as repeated treatments, to determine the best combination for obtaining the desired degree of brush kill. We included those herbicides that had been most effective in hand spraying trials.

We conducted the herbicide tests on many large plots so as to obtain results that would simulate closely the effects of large-scale spray jobs, to provide considerable acreage for visual judgment of results each year, and to allow evaluation of various treatments under a wide assortment of local conditions.

The tests were made on areas cleared by machine during the year before we began our spray applications. We applied the sprays during summer months when shrub plant growth was considered at near optimum stage for killing small plants. This approach allowed direct extension of results to other mechanically cleared areas where herbicide applications were to be used as a part of site preparation ahead of pine planting. We also could estimate and compare effects of the different spray treatments for controlling brush on areas recently planted to pine, although in such uses the spraying was delayed until about September 1 to avoid undue damage to the young pines, as determined by concurrent studies (Bentley 1967).

STUDY AREA AND PROCEDURES

The three study areas included a burned-over pine forest site and two manzanita brushfield sites. The pine forest, near Foresthill on the west slope of the Sierra Nevada, had burned in 1960. All merchantable timber had been removed and the debris windrowed or piled with bulldozers during 1961 and early 1962. The brushfields, located above Viola and near Mount Shasta in the Cascades, had been cleared by heavy bulldozing in 1961.

At each location two blocks of 54 large rectangular plots were laid out to allow use of tractor-drawn spray equipment. Each plot was 66 by 132 feet (20.1 by 40.2 m) with an area of 0.2 acre (0.08 ha), making 10.8 acres (4.37 ha) per block. The total of 324 plots in the study occupied 64.8 acres (25.93 ha)—an appreciable acreage for observational data.

Herbicide Treatments

The sprayers were equipped with hoses for hand applications and with a collapsible boom which could be extended for broadcast applications. Nine sequences of hand sprays (H) and broadcast sprays (B) were tested as follows:

1962	1963	1964	Total
B	—	—	1
B	B	—	2
B	B	B	3
B	B	H	3
B	H	—	2
B	H	H	3
H	—	—	1
H	H	—	2
H	H	H	3

The three sprays were applied in consecutive years because of the need to complete the study within a 3-year period, even though alternate year spacing of certain spray treatments might be more effective.

Low-volatile esters (butoxy ethanol) of 2,4,5-T and 2,4-D were tested singly and as a 1:1 mixture of the two at different dosages as follows:

Herbicide	Rate	Dosage lb a.e. ¹
2,4,5-T	Moderate	4
2,4-D	Moderate	4
1:1 mix	Moderate	4
1:1 mix	Light	2
1:1 mix	Heavy	8B,16H

¹Pounds acid equivalent per acre for broadcast spraying and per 100 gallons for hand spraying (1 lb/acre = 1.12 kg/ha; 1 lb/gal = 1.2 kg/1000 l).

For the low-volume broadcast sprays applied with a boom, the herbicide was mixed with 0.5 gallon of diesel oil and sufficient water to make 20 gallons of emulsion per acre (187 l/ha). For the hand sprays, the herbicide was mixed with 1.0 gallon of diesel oil, and water was added to make 100 gallons of emulsion. In hand spraying, the herbicide was carefully applied to the leaves and stems of sprouting plants and the larger seedlings to the point of drip-off; additionally, the wand was passed over dense stands of very small seedlings to give a heavy broadcast coverage, but no attempt was made to locate and spray all small individual plants.

The five herbicide-dosage treatments were applied in each of the nine application method (hand or broadcast spray) sequences, so that a total of 45 spray treatments and 9 unsprayed plots were located at random in

each 54-plot block. Thus each method sequence was applied on 10 plots at a location, but each specific method-herbicide-dosage treatment was applied only 2 plots per location.

The herbicide applications were started each year June at Foresthill, continued at Viola, and completed Mount Shasta in late July or early August. Air temperatures were favorable for herbicide reactions at times, although on some plots either the temperature or wind movement was above that allowable for aer applications. Spraying was discontinued if spray might drift excessively onto adjacent plots.

Brush Plant Records

Uneven disturbance of the soil during bulldozer operations resulted in variable stands of brush regrowth on the study areas, particularly at Foresthill, where logging and debris piling caused spotty removal of regrowth already established in 1961. Because of variations in brush plant numbers from plot to plot, at the start of herbicide treatment in 1962 we counted plants on each plot. This count was the base for determining changes caused by treatments.

In 1962 we recorded number of plants, by species and age, that were present at the time of initial spraying. In 1963 and in 1964 we tallied the new seedlings that had become established during the current year, even though they might die from current herbicide treatment or from natural causes. In 1965 we counted the older plants surviving the different treatments, and the new seedlings of the year. From these records, we summarized for each plot the number of plants present at the start of spraying in 1962, total number of plants established up to termination of spraying, and percent survival in 1965 of all plants established before 1965.

In determining average percent survival of plants under any one treatment, we based the average on total number of plants established in all plots receiving the treatment, and total number of surviving plants in those plots. The number of plants established was about the same for each treatment when the average was based on more than four plots per treatment. However, when the average was based on only two to four plots per treatment, the number of plants established per treatment was highly variable.

Counts of shrub plants were made on one half of each plot, in a 0.1-acre strip 33 feet wide along the centerline of the plot. This strip was divided into five 0.02-acre quadrats marked with short stakes. Generally, all plants of a particular species-age class within a quadrat could be readily located and tallied, but in extremely dense stands of more than approximate

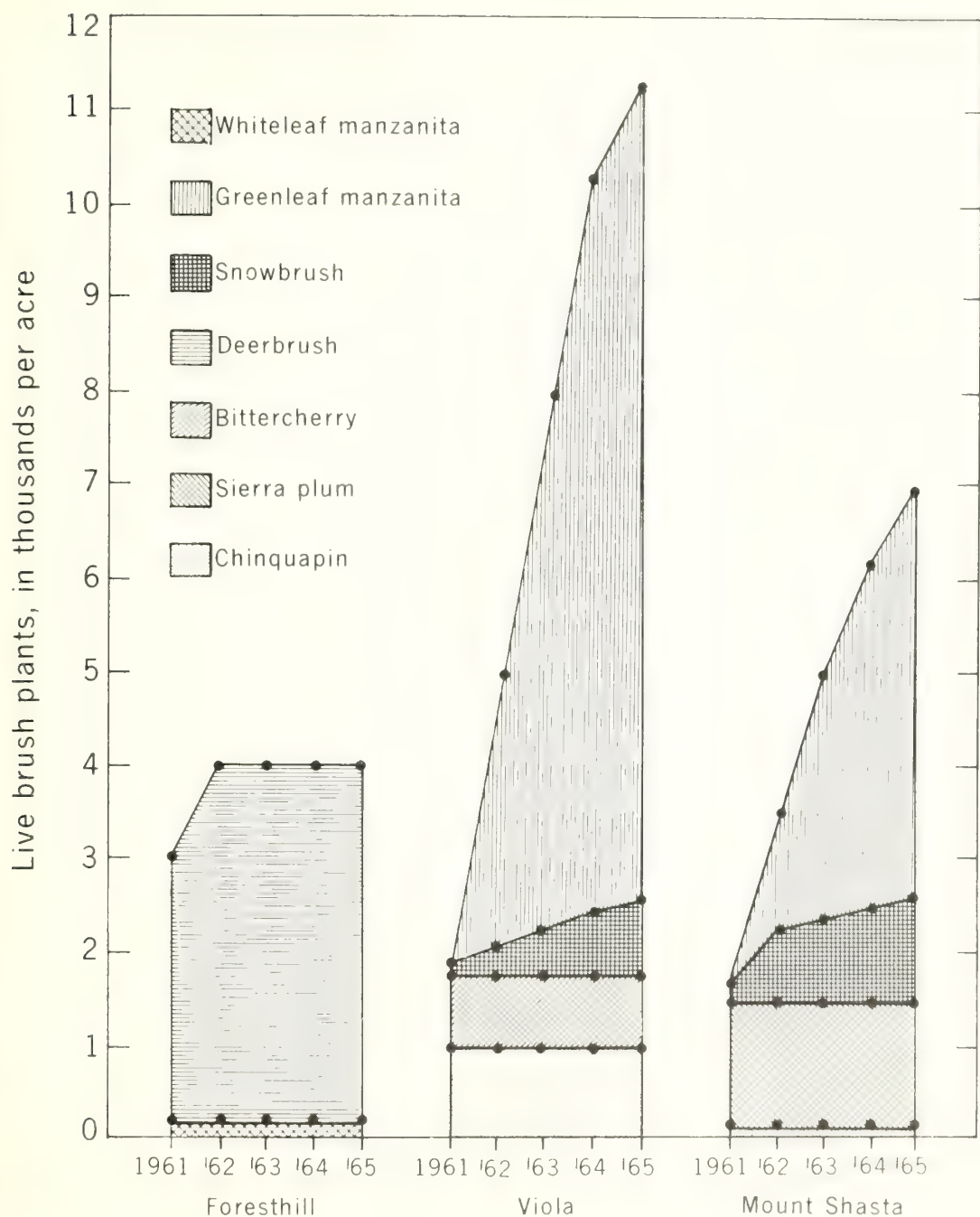


Figure 1—Typical patterns of brush plant establishment from 1961 through 1965—on pine forest burned over in 1960 at Foresthill, and on brushfields cleared by bulldozing in 1961 at Viola and Mount Shasta. (Data on bearclover at Foresthill are not included.)

200 plants per quadrat, estimates were made from counts on four representative milacres. Plants were easily found in all years on sprayed plots where brush had been kept to small size, but estimates were less

precise for 1963 and 1964 in the dense stands on unsprayed plots; in some plots, the total number of plants estimated for all preceding years was less than the number actually counted in 1965.

PATTERNS OF BRUSH REGROWTH

The typical pattern of brush plant establishment from 1961 through 1965 on each study area is shown in figure 1.

Shrub Species, Foresthill

Deerbrush (*Ceanothus integerrimus* H. & A.) was the dominant shrubby species on most plots. The seedlings established in 1961 and 1962 were growing vigorously by summer 1962. On unsprayed plots, the plants continued growth to heights of 3 to 6 feet by 1965; the spreading branches covered much of the ground in typical stands, and many small plants had died under the dense canopies. For all plots, the average number of plants in 1962 was about 3800 per acre. On unsprayed plots, 63 percent of this number survived in 1965.

Whiteleaf manzanita (*Arctostaphylos viscida* Parry) also was present on most plots. The plants were vigorous but of lower stature than deerbrush. Though occasionally dense, stands averaged only about 180 plants per acre for all plots in 1962. A few additional plants became established by 1965, and average survival on unsprayed plots was 75 percent of the original plants.

Deerbrush and manzanita together produced rather full brush covers by 1965 on most unsprayed plots; they provided excessive competition to young pines.

Bearclover (*Chaemaebatia foliolosa* Benth.), a low-growing semishrub, occurred in patchy stands. Where present as almost solid mats, this species represented extremely heavy competition to pine seedlings. The individual plants could not be consistently identified and counted; the tremendous numbers of small shoots tallied on the plots were not comparable to plant counts of other species. Consequently, plant numbers for bearclover have been omitted from the data summaries in this report. Reactions of this important species to herbicide treatments, however, were similar to those shown in the data for whiteleaf manzanita.

Other than bearclover, the most common brushy plants reproducing as sprouts were scattered stumps of black oak (*Quercus kelloggii* Newb.). This species was fairly well controlled by the herbicide treatments most effective on whiteleaf manzanita.

In summary, at Foresthill most plants of the regenerating brush stand were established by 1962.

Shrub Species, Viola and Mount Shasta

In these areas, large numbers of new brush seedlings continued to become established each year. Seed had remained irregularly mixed within the upper soil even

though the objective of the heavy bulldozing had been to push all brush plants, duff, seed, and several inches of topsoil into the windrows.

Greenleaf manzanita (*A. patula* Greene) was the shrub present in greatest number on the Viola plots in 1962. Taking all Viola plots together, an average of about 100 plants per acre were sprouts from old root crowns; the remainder were new seedlings. Seedlings became established at more than 2500 per acre in 1962, 1963, and 1964, with about 1000 new plants in 1965, making an average total of 8900 per acre by 1965. Seedling mortality each year was inconsequential.

Snowbrush (*Ceanothus velutinus* Dougl. ex. Hook) also was widely distributed in 1962 as sprouts from old root crowns, averaging about 100 per acre. But it occurred mainly as new seedlings which continued to be established each year. Plant numbers were much lower than for manzanita; only about 800 snowbrush plants per acre had become established by 1965 as an average for all Viola plots. However, the fewer plants of this vigorous species produced as much, or more, total plant crown, and probably represented more competition to pines during the first few years, than did the manzanita.

The dominant sprouting species were bittercherry (*Prunus emarginata* Dougl.) and chinquapin (*Castanopsis sempervirens* [Kell.] Dudl.). These vigorous species were potentially strong competition to pine if left uncontrolled, even though there were fewer plants per acre than manzanita.

Bittercherry was present on about half of the Viola plots as numerous sprouts from roots severed during the bulldozing operation. The average of approximately 800 plants per acre on those plots where the species occurred was much higher than the average number of old plants present before bulldozing. The new bittercherry plants were small and poorly rooted when the tests were started in 1962.

Chinquapin was widely distributed as vigorously growing sprouts from old root crowns remaining intact after bulldozing. The average number of plants of this tough species, about 950 per acre, was sufficient to produce a rather dense cover if left uncontrolled.

On the Mount Shasta plots, brush regrowth was similar to that at Viola, except that plant numbers for manzanita averaged only about one-half as many. But the stands still were sufficient to produce a very dense brush cover on most of the area. The number of snowbrush plants, an average of about 1050 per acre, was greater than at Viola.

Sierra plum (*Prunus subcordata* Benth.) was widely distributed and was the only important sprouting

species. The plants, averaging 1400 per acre, had sprouted from severed old roots, but had not developed strong new root systems.

Chinquapin, present as scattered plants on less than half the plots, on an average of about 80 plants per acre, was not an important species on this area.

CONTROL OF BRUSH REGROWTH BY TREATMENT

Results of the treatments are reported for single and repeated applications, hand and broadcast applications, different herbicides, and different dosage rates.

Single Herbicide Application

A single herbicide application in 1962 killed a high percentage of the brush plants that had become established before the spraying, with the exception that poor kill resulted from broadcast sprays at the lightest dosage rate. The control of initial brush regrowth, however, even on plots where herbicides were most effective, was considered adequate for only the most susceptible brush plants. These were small seedlings of deerbrush, greenleaf manzanita, and snowbrush; weak crown sprouts of manzanita and snowbrush; and weak root sprouts of bittercherry and Sierra plum. Plants generally not killed by a single application included the most resistant species: whiteleaf manzanita seedlings; bearclover sprouts; and the vigorous crown sprouts of manzanita, snowbrush, and chinquapin. A single application in 1962 at Viola and Mount Shasta gave poor overall control because many new seedlings became established in succeeding years (*fig. 2*). Survival by species varied (*fig. 3*).

Most plants of deerbrush, the dominant species, were killed by a single spray of adequate dosage, but more than half of the resistant whiteleaf manzanita seedlings survived. Most stands of bearclover fully recovered after a single spray application. For the 20 plots sprayed once at Foresthill, an average of more than 700 plants per acre (exclusive of bearclover) were still present in 1965.

A single spray in 1962 killed about one-half of the plants that became established on the plots at Viola and Mount Shasta. Survival was greatest for greenleaf manzanita and snowbrush because many new seedlings became established after 1962. Survival was lowest for bittercherry and Sierra plum, all of which were established as poorly rooted sprouts ahead of the 1962 spray treatment. At Viola, chinquapin, a tough sprouting species, showed 41 percent survival of the crown sprouts present in 1962.

Total number of plants surviving in 1965 on plots receiving a single application averaged 4671 per acre

In summary, on the bulldozed brushfields at Mount Shasta and Viola, there was a need to (1) control the full stands of sprouts and numerous seedlings present at the initial spraying, and (2) space follow-up sprays to control the continuing establishment of new seedlings during the next 3 years.

for 20 plots at Viola and 3716 for 20 plots at Mount Shasta. In large part these were seedlings established after the 1962 spray, but also included sprouts of chinquapin and other resistant plants. In addition, nearly 1000 new seedlings per acre were established in 1965 at each location.

At all three locations, we concluded that at least two or three repeated sprays were needed to provide adequate control of the more resistant brush species and to kill the numerous small seedlings established after the first spray treatment.

Repeated Herbicide Applications

At Foresthill, the second and third sprays reduced the brush stands to low levels (*fig. 2*). Deerbrush was

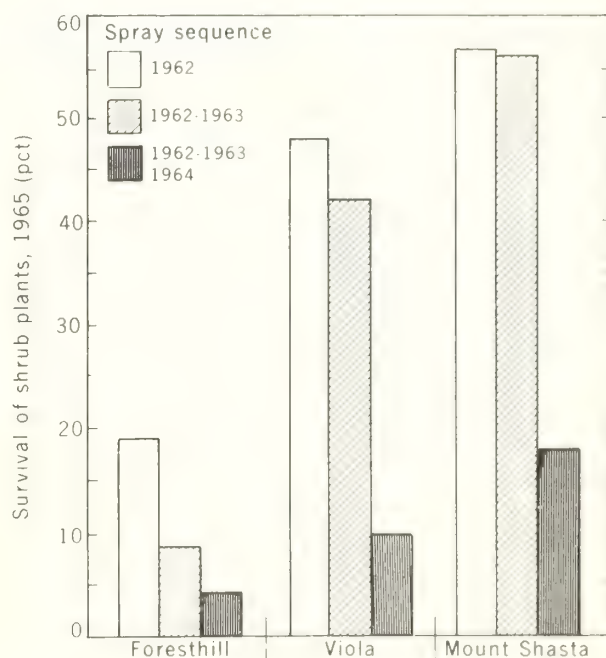


Figure 2—Survival in 1965 of shrub plants (all species except bearclover) on herbicide treatment plots was strongly influenced by number of repeated sprays. (Average survival is based on plants established up to termination of spraying in 1964, on plots hand or broadcast sprayed with three herbicides at three dosages, 20 to 40 plots per treatment average.)

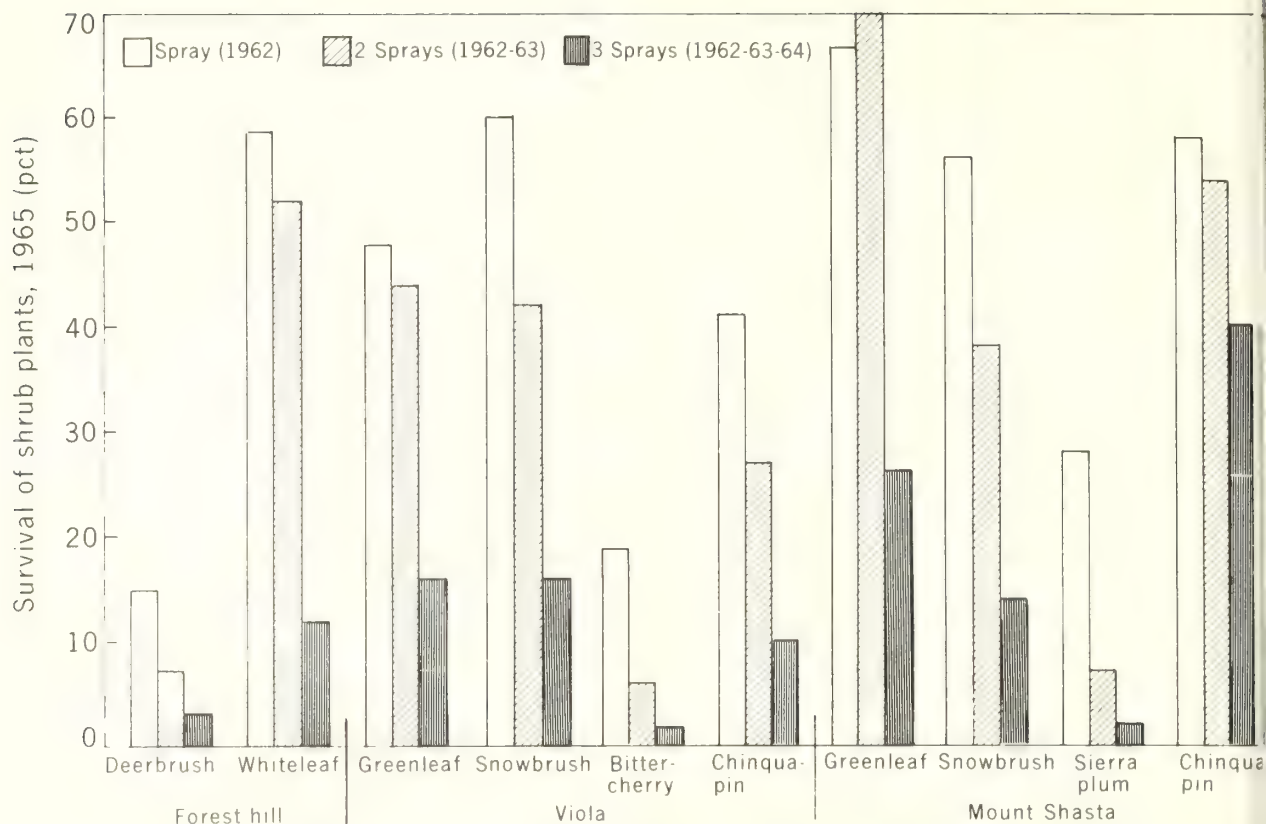


Figure 3—Survival in 1965 of individual shrub species on all herbicide treatment plots was influenced by resistance of species as well as by spray sequence. (Averages are based on same plots as in fig. 2.)

nearly eliminated from 29 plots sprayed twice and 40 plots sprayed three times (fig. 3). Plants surviving after three sprays were mainly on plots broadcast sprayed at the low dosage of 2 pounds per acre. Three sprays were required for good control of whiteleaf manzanita seedlings; half of the plants survived on plots sprayed twice. Bearclover also required three sprays for full control, although two sprays were much more effective than a single application.

At Viola and Mount Shasta the two sprays, applied in 1962 and 1963 on 30 plots at each location, produced low kill of the total brush stand (fig. 2). Most of the surviving plants were new manzanita and snowbrush seedlings established in 1964, plus small 1963 seedlings missed by hand spraying (fig. 3). At Viola, the average number of plants surviving in 1965 was 4363 per acre, including 3779 plants of greenleaf manzanita. At Mount Shasta the 3667 surviving plants per acre included 3198 manzanita plants, mainly new seedlings. Two sprays nearly eliminated sprouts of bittercherry and Sierra plum. But 27 percent of the chinquapin sprouts still survived at Viola, and 56 percent of the few plants at Mount Shasta were still alive.

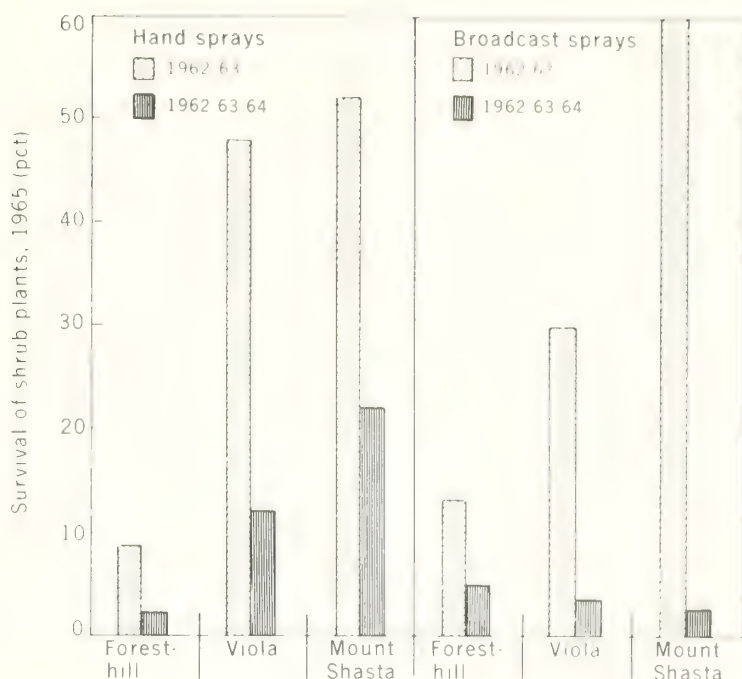
On 40 plots sprayed three times at Viola and 40 plots

at Mount Shasta, the repeated applications greatly increased plant kill over the two applications (fig. 2). The lower survival for plots receiving three sprays was caused mainly by control of manzanita and snowbrush seedlings established in 1963 and 1964. Better control also was obtained from three sprays on sprouting species, particularly for chinquapin which was reduced to only 10 percent survival at Viola (fig. 3). Although a high degree of control was obtained from three sprays, a large number of small plants still remained in 1965. For example, at Viola an average of 1133 surviving plants per acre included 898 manzanita plants, and at Mount Shasta the average survival of 1030 plants per acre included 808 manzanita plants. In addition, an average of nearly 1000 new seedlings per acre became established in 1965 at each location.

Hand Spray vs. Broadcast Sprays

Hand spraying effectively reduced the brush plants that were established by 1962 but missed many of the small plants established in 1963 and 1964. Thus, hand

Figure 4—Survival in 1965 of shrub plants established by 1964 on hand-sprayed plots is contrasted here with that on broadcast-sprayed plots. (Averages are based on plots sprayed twice or three times, 9 or 10 plots per treatment average.)



sprays were very effective at Foresthill where most plants were established by 1962 (*fig. 4*). In contrast, on plots hand sprayed twice at Viola and at Mount Shasta, about half of the plants survived. Three hand sprays were much more effective.

At Foresthill, hand spraying produced more complete kill than did broadcast spraying, although both application methods were effective (*fig. 4*). At Viola and Mount Shasta, where many new seedlings became established in 1963 and 1964, broadcast spraying was clearly more effective than hand spraying, particularly when plots were sprayed three times—1962, 1963, and 1964. For ten plots at Viola, three broadcast sprays reduced the total brush stand to 4 percent average survival, and on nine plots at Mount Shasta, to only 3 percent.

Because adequate brush control can be obtained from broadcast spraying, this method has practical advantages over hand spraying for work on large areas—cost is much lower and it is possible to cover more acreage during the short season when the brush plants are most susceptible to herbicides.

Using hand spraying as a follow-up treatment after broadcast sprays on the test plots did not appear to have any practical advantage, particularly where broadcast spraying was much more effective in killing dense stands of newly established brush seedlings. Follow-up hand spraying might be needed in some situations: for example, in reducing brush cover over many years on fuelbreak strips within pine plantations. In other

situations, hand spraying might replace broadcast spraying if danger of herbicide drift from aerial sprays was a critical problem, or where spraying during certain seasons required selective herbicide placement to avoid damage to pines.

Different Herbicides

Each of the three herbicides produced essentially the same degree of shrub control. We did not observe any consistent differences in the field, and none were shown by the data summaries. For one comparison, we used all plots receiving the so-called "moderate dosage"—4 pounds a.e. per 100 gallons or 4 pounds a.e. per acre—which gave large samples of 17 to 54 plots for each herbicide. The data for these samples showed essentially the same percent survival of brush plants for each of the three herbicides on each study area (*fig. 5*).

Data from those plots receiving either two or three broadcast applications at the 4-pound rate showed considerable variation because there were only two plots per sample of each herbicide, but no consistent differences between herbicides were apparent (*fig. 5*). The three spray applications (1962-63-64) produced a uniformly high degree of brush control for each of the three herbicides at each location, except for greater plant survival on plots sprayed with 2,4-D at Forest-hill. Significance of this variation was not determined.

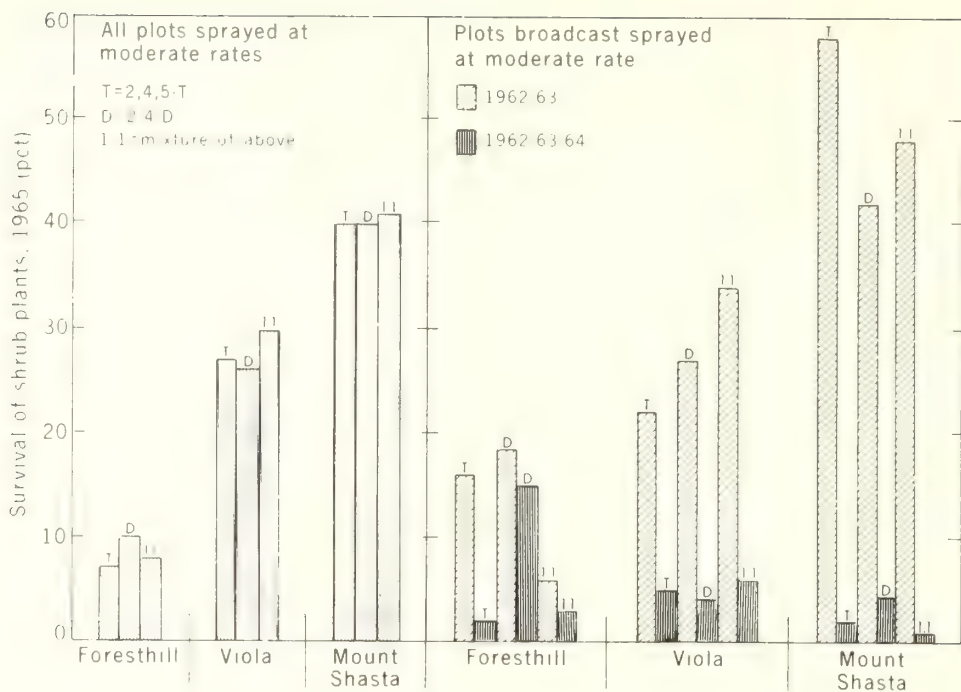


Figure 5—Survival in 1965 of shrub plants established by 1964 is contrasted here for plots sprayed with three different herbicides. (Averages for all plots, hand-sprayed plus broadcast-sprayed, are based on 17 to 54 plots per treatment sample; but averages for plots broadcast sprayed twice or three times are based on only two plots per sample.)

The variability in data from plots receiving two sprays (1962-63) appeared to be caused mainly by large differences between plots in numbers of brush seedlings established in 1964 after spraying had been terminated in 1963. All herbicides appeared to be effective on plants established prior to spraying.

Because there was little difference between herbicides in control of small brush regrowth on the plots, in subsequent site preparation spraying on pine plantations the cheaper 2,4-D has been used either alone or in combination with 2,4,5-T. A 1:3 mixture of 2,4,5-T and 2,4-D has been recommended for stands of small brush plants, and a 1:1 mixture for stands having larger plants of chinquapin and snowbrush, or other species assumed to be susceptible to 2,4,5-T.

The more expensive 2,4,5-T has been recommended for release sprays over ponderosa pine seedlings because the pines have much greater tolerance to this herbicide than to 2,4-D.

Different Broadcast Dosage Rates

The effects of herbicide dosage rate were best observed in 1963 on those plots broadcast sprayed in 1962. At this time the brush kill was much more irregular on plots receiving the 2-pound rate than on plots sprayed at 4-pound or 8-pound rates. On some

plots, the spray at 2 pounds a.e. per acre appeared to have little effect; on other plots the vegetation was affected the first year but had recovered by 1965 if the plots had not been resprayed.

On all plots that received repeated applications, the apparent differences caused by dosage rate were largely eliminated by 1965. At Foresthill, however, the 2-pound rate was still noticeably less effective than the heavier rates in killing well-established deerbrush seedlings, which have ordinarily been considered relatively susceptible to herbicides (*fig. 6*). At Viola and Mount Shasta, where the brush regrowth was dominated by weak seedlings established during the course of spraying (*fig. 1*), all herbicide dosage rates effectively controlled the regrowth on plots sprayed three times (*fig. 6*).

On plots sprayed twice at Viola and Mount Shasta, plant survival was high regardless of herbicide dosage per acre. Greater survival at higher dosages probably reflected greater numbers of new plants established in 1964, rather than differences in effects of herbicide dosage rates. The two-plot samples were too small for true evaluation of individual dosage rate on plots where variable numbers of plants became established after spraying was terminated.

On plots broadcast sprayed three times at each location, the 8-pound rate produced more consistent plant

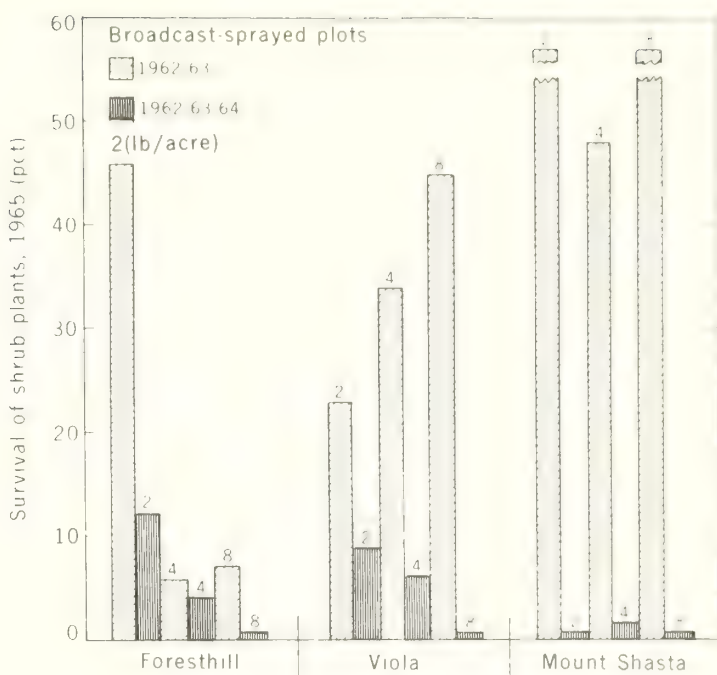


Figure 6—Survival in 1965 of shrub plants established by 1964 is contrasted here for plots broadcast sprayed twice or three times at different herbicide dosage rates. (Averages are based on plots sprayed with 1:1 mix of 2,4-D, and 2,4,5-T, two plots per treatment sample.)

kills plot by plot, but clearly was more than was needed for adequate plant control. The 8 pounds a.e. of herbicide could be spread over at least two yearly applications at lighter rates to produce greater effect from the same amount of herbicide.

A relation between initial dosage rate and the effectiveness of follow-up sprays on brush plants with dense foliage has been observed on many spray tests in California and was well illustrated by vigorous deerbrush seedlings sprayed at Foresthill. On a 2-year-old plant with densely foliated crown in 1962, the initial broadcast spray at the 2-pound rate typically killed only about one-third of the total crown area, the 4-pound rate killed foliage deeper into the crown, and the 8-pound rate killed all, or most, of the total crown. An initial saturation hand spray also killed the total crown on almost all deerbrush plants. Follow-up sprays killed most of the plants in the 4-pound or 8-pound initial

spray group, and the hand-sprayed plants. On plants in the 2-pounds-per-acre initial spray group, however, the repeat sprays at this low rate did not kill all parts of the crown, and many of these plants were still alive in 1965 after three spray applications. In contrast to the results on vigorous plants, the less vigorous deerbrush plants—those with open crowns in 1962—were eliminated by three sprays at any of the dosage rates; most of these plants were killed by the initial spray.

These results suggest that follow-up applications of 2 to 4 pounds per acre, after an initial application at the 4-pound rate, probably would produce effective control. A total of 8 to 10 pounds a.e. of herbicide spread over three applications would be more effective than a single heavy application on deerbrush, and very much more effective on the associated resistant species—whiteleaf manzanita and bearclover.

DISCUSSION

Percent survival of established plants serves as a good comparison of effects from different herbicide treatments; as in our tests, it is the standard comparison in studies where numbers of plants differ from plot to plot. Number of surviving plants per acre would be a more meaningful basis for evaluating treatments because this measure represents the nucleus remaining for potential development of a future brush stand. Use of number of plants, however, is limited to fairly uniform brush stands, or to comparisons involving a sufficient number of plots per treatment sample. As

illustrated by results on plots at Mount Shasta (*fig. 7*), the data for percent survival and for number of surviving plants, based on 9 to 40 plots per sample, produce similar curves. By either basis of comparison: one spray reduced brush stands by about one-half; two sprays added little to the apparent herbicide effectiveness, because many new seedlings became established after the last spraying; but a third spray killed many of these seedlings and reduced the brush stand to a low level.

Although either of the above treatment comparisons

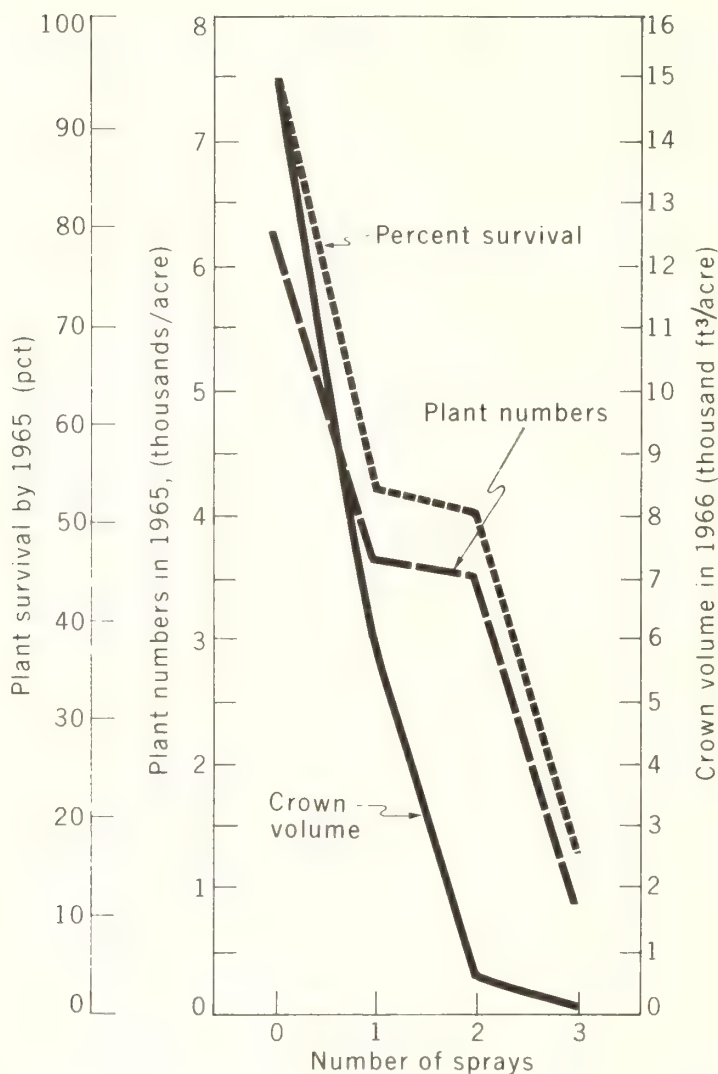


Figure 7—Relative effects of one, two or three spray applications are shown here by percent survival of plants and number of surviving plants per acre; these measures are contrasted with a measure which better expresses reduction in number, size, and vigor of shrub plants—crown volume of surviving plants. (Plant counts and percent survival are based on shrub plants established by 1964 on all plots at Mount Shasta; crown volume is measured on plants present in 1966.)

is useful in specific situations, neither fully evaluates the extent to which a brush cover has been reduced by herbicide treatment. Reductions in size and vigor of surviving plants also should be taken into account. Crown volume of the surviving plants—measured as cubic feet per acre (ft^3/acre)—is one expression of size and vigor of a brush stand. Measurements on the Mount Shasta plots, in *figure 7*, show that either two or three sprays effectively held down volume of brush cover and greatly reduced its competitive effects, even though many plants still remained.

One spray reduced brush crown volume by more than one-half. Two sprays lowered the volume all the way down to about $450 \text{ ft}^3/\text{acre}$ in 1966—a ratio of 3 to 100 when compared to unsprayed plots—even though some 4500 plants per acre still survived. Three sprays gave more complete brush control with about $90 \text{ ft}^3/\text{acre}$ average crown volume in 1966, but nearly 2000 small plants per acre remained.

The crown volume curve gives a much better mea-

sure of the effectiveness of two sprays than does either the percentage survival curve or plant numbers curve (*fig. 7*). Measurements of total brush crown volumes, as described by Bentley and others (1970), expressed competitive effects of the brush stands. On plots having variable densities of brush, the total crown density was closely related to survival and growth of young ponderosa pine seedlings on the plots (Bentley and others 1971). Where the pines were planted on a bulldozed area, their growth was outstandingly better on those plots having total brush crown volume below 5000 to $10,000 \text{ ft}^3/\text{acre}$ at the end of the first 5 years after bulldozing.

In summary, on almost all plots at the three locations, two or three spray treatments obviously held brush crown volumes to a very low level, regardless of the initial brush stand densities. Repeated spraying kept the brush well below the level where it would have competed materially with pine seedlings planted 1 or 2 years after land clearing.

CONCLUSIONS

The conclusions made now, 10 years after completion of the administrative study of herbicide application, are based not only on the test plots but also on helicopter spraying of many pine plantations in northern California. With the test results, this practical experience helped to identify the significant factors in brush control on such areas.

In the tests, a high degree of brush control was obtained from the most effective plot treatments because spraying was started when regrowth was small, the spraying was done during the summer when air temperatures and soil moisture were favorable for herbicide reactions, and spraying was continued in consecutive years before the plants fully recovered from preceding sprays.

At some locations, helicopter spraying produced less satisfactory control, which could be attributed to one or more unfavorable conditions: (1) initial spraying was not started until brush regrowth was large and well established, more than 2 years after land clearing; (2) sprays were applied late in the season, in September or later, when low temperatures or plant moisture stress reduced herbicide effectiveness; or (3) initial spraying was delayed a few years and sprays were applied late in the season—making control particularly difficult. Practical experience showed that these disadvantages could be largely overcome by applying maximum recommended dosages, particularly in the initial spray, and by applying as many follow-up sprays as required to produce the desired degree of control. Better brush control was obtained, with less total herbicide, on the areas where spraying was started when brush plants were small, and follow-up sprays were applied in consecutive years or in alternate years.

Plant Susceptibility to Herbicides

Susceptibility generally depended on size of plant crown and development of root system rather than on plant species. The following description applies to brush regrowth commonly found on pine plantations in northern California.

Highly susceptible plants—those most readily killed by a single broadcast foliar spray—included

1. Small seedlings in first or second growing season, with open crowns and poorly developed root systems; usually under 12 inches in height. Species included greenleaf manzanita, snowbrush, and deerbrush.

2. Root sprouts with open crowns, not yet well established after bulldozing. Species included bittercherry and Sierra plum.

3. Small, weak crown sprouts with open crowns, established during first 2 years after burning or bulldozing. Species included greenleaf manzanita and snowbrush.

Less susceptible plants—those seldom killed by a single spray, but tending to recover rapidly and needing one or more follow-up sprays—included

1. Seedlings of resistant species, notably whiteleaf manzanita on the test plots.

2. Large, densely foliated seedlings of most brush species, usually more than 2 years old and having well-developed root systems. On test plots they included greenleaf manzanita, snowbrush, and vigorous deerbrush seedlings.

3. Vigorous sprouts from root crowns having well-developed root systems. Resistant species included chinquapin of all ages, and older sprouts of greenleaf manzanita and snowbrush.

4. Sprouts of bearclover.

A mixture of brush plants always occurs on plantations, with more than one kind present in numbers sufficient to be highly competitive if not well controlled. Control of the most susceptible may release more resistant plants that eventually will provide strong competition with pines. Thus, herbicide spray treatments need to be planned to control the less susceptible species. Our tests indicated that repeated sprays aimed at control of chinquapin, bearclover, whiteleaf manzanita, or large vigorous snowbrush plants—depending on which is the key problem plant—will provide adequate control of the total brush cover.

Spacing of Herbicide Applications

A single broadcast foliar spray has seldom, if ever, produced the desired degree of brush control on pine plantations. An exception could be a stand of the most susceptible plants, where few new plants became established after the first spray. One or more follow-up sprays will usually be needed. However, if follow-up sprays have been planned, they can be terminated once the brush stand has been reduced in crown volume or plant numbers to meet the aim of the plant control operation.

The number of sprays actually needed depends on the age and size of the brush plants at the time of the

initial application, the herbicide dosage rate in each application, and spacing of the follow-up sprays.

Spacing of follow-up sprays in consecutive years, as in our plot tests, was effective, but spraying in alternate years also produced good brush control on some larger areas. On the plots at Foresthill, where nearly all brush plants were established by 1962, the consecutive-year spraying probably was best. The initial application was needed by 1962 because the brush plants already were fairly large and densely foliated; consecutive-year sprays gave good brush control before the plants had recovered. On the bulldozed brushfields at Viola and Mount Shasta, where many new seedlings were established each year through 1965, the three sprays obviously would have been more effective if spread over more than 3 years. Experience from spraying larger areas of manzanita brushfields indicated that spacing could well have been 1962-63-65, 1962-64-66, or 1963-64-66, for three sprays, or 1962-64 or 1963-65, for two sprays.

In practical operations, the restricted time and funds available in any one year often prohibit consecutive-year spraying of all areas where this spacing might be desirable. Alternate-year spraying often is the closest allowable spacing. Wider spacing should be avoided if possible—it does not make the most effective use of herbicides.

Results from large-scale spray operations definitely showed that the most effective control of brush regrowth was obtained by applying the initial spray during the first 2 years after removing the original brush cover. Delay of the initial spray until the brush plants were better established required more herbicide per application, and satisfactory brush control was less assured.

Bulldozed brushfields usually were ready for spraying the next year after brush removal. Brushfields burned during the spring could be effectively sprayed in early September, but delay of spraying until the next year produced more brush kill from the initial spray. However, if planting of pines is to be delayed until the second season, a site-preparation spray could well be applied during the first season, to reduce possible injury to planted pines.

Selection of Herbicide

The plot tests did not show consistent differences in brush kill from applications of 2,4-D or 2,4,5-T or a 1:1 mix of the two—provided sufficient amounts were applied in repeated applications. Good brush control also has been obtained from each of these herbicides applied by helicopter on large areas. On some areas

greenleaf manzanita has appeared to be particularly susceptible to 2,4-D, and less sensitive to 2,4,5-T. Well-established seedlings of mariposa manzanita are definitely resistant to 2,4,5-T and susceptible to 2,4-D, particularly during late summer and fall.

In practical operation, either 2,4-D alone or in mixture with 2,4,5-T (1:1, 2:1, or 3:1) has been used for site-preparation sprays ahead of pine planting. Because of the well-known greater resistance of ponderosa pine to 2,4,5-T, it has been used for “release sprays” over young pines. It is applied after pine buds are fully formed and have a protective resinous coating, typically about September 1 in northern California.

Herbicide Dosage Rates

The effective minimum dosage rate, in plot tests and large-scale spraying, has depended on age and size of brush plants and on degree of recovery from a preceding herbicide treatment.

A dosage of 2 pounds a.e. per acre produced good control of resistant brush plants on plots sprayed three times in successive years, starting when the plants were still small. The first spray usually produced uneven effects, but repeated applications finally killed most of the plants. In other trials on more advanced regrowth, an application of 2 pounds per acre produced negligible effects. All observations indicate that a 2-pound dosage rate is effective only if applied as an initial spray during the first year of brush regrowth and on brush stands kept at a very low vigor and small size by repeated spraying. Application of this low dosage on more advanced brush regrowth may well be wasted effort and expense.

Dosage of 4 or 8 pounds a.e. per acre produced good brush control from two or three applications on the test plots. The 8-pound rate obviously was greater than required; spreading this amount over 2 or 3 years would be advisable.

In practical operations, dosage rates of 3 or 4 pounds per acre have been commonly used and generally effective. The higher rate was needed on well-established brush regrowth. A satisfactory level of brush control was obtained where repeat sprays were applied as needed to reach the control objectives.

A primary aim on pine plantations ordinarily will be reduction of brush crown volume to a level that will allow full growth of planted pines. But this must be balanced against the level of brush control required in meeting other land use objectives. Thinning of the brush cover to allow easy access for future silvicultural activities may be one aim. Reduction of total woody

vegetation to improve fire control possibilities, at least on fuelbreak sites, can be another objective. Leaving some brush plants as readily accessible browse or cover for wildlife ordinarily should be an important aim during establishment of new plantations. The brush left for cover, usually in excess of that desired on all of a plantation, can be on areas within or adjacent to the plantations. Herbicide dosage rates and numbers of applications can be adjusted on all or any part of a plantation area to produce the desired results.

Herbicide Application Method

Repeated broadcast spraying was more effective than repeated hand spraying on the test plots for controlling the many small brush seedlings often missed during hand spraying. A single hand spray, which

saturated the foliage, was more effective than a low-volume broadcast application in killing resistant plants with dense crowns. However, after plant crowns had been reduced by an initial spray, either application method produced adequate brush control.

Broadcast spraying obviously is the most efficient application method on large areas, and it is the only feasible method for covering large areas during short periods when the brush plants are most susceptible to herbicides. Hand spraying may have a place, however, in situations where broadcast spraying by helicopter or ground-rig boom sprayers are not possible or not advisable. Hand sprays can be used for follow-up herbicide applications or fuelbreak areas of limited acreage within plantations, or on areas where spraying is required early in the season at a time when pines may be excessively damaged by broadcast sprays.

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1978. **Control of brush regrowth with herbicides on pine plantations in northern California.** Res. Paper PSW-134, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

On large plots cleared in 1961 at three California mountain locations, different herbicide treatments were applied once, twice, or three times in consecutive years, beginning in 1962. Results were evaluated in 1965. A single spray was unsatisfactory; only the initial seedlings and weaker sprouting plants were killed, and many new seedlings became established in 1963 and 1964. Two consecutive sprays greatly reduced brush competition, but many of the vigorous sprouts survived along with numerous new seedlings. Three sprays killed almost all of the most resistant plants; only very thin brush stands of low vigor survived. Broadcast sprays were more effective than hand applications in killing dense stands of seedlings. Either 2,4-D or 2,4,5-T, or a mixture of the two, was effective in repeated applications at 3 to 4 pounds, a.e., per acre. Dosages of 2 pounds generally were ineffective; 8 pounds was excessive. Test results were successfully applied in helicopter sprays in subsequent years.

Oxford: 441—414.1:176.1 *Arctostaphylos* spp. + 232.214:176.1 *Arctostaphylos*

Retrieval Terms: Brush control; manzanita; herbicides; site preparation; plantations; ponderosa pine.

Bentley, Jay R., and Kenneth M. Estes

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A LANDSCAPE INVENTORY FRAMEWORK: scenic analyses of the Northern Great Plains

R. Burton Litton, Jr.

Robert J. Tetlow



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We are grateful for the assistance of colleagues at the University of California, Berkeley, who were responsible for much of the basic work of the study. William Garnett, professor of design, flew the low-level air photo transect and provided color photography. Graduate students in landscape architecture participating were Susan Boyle, Jean Imai, and Nancy Owens, who did a majority of the field work and ground photography, and Lawrence Diamond, who, with Jean Imai, was a research assistant during 1974-75. Nancy Owens did the field sketches.

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CONTENTS

	<i>Page</i>		<i>Page</i>
Introduction	1	Landscape Unit	51
Field Observations	3	Scale	52
Land Form Characteristics	8	Boundaries and Edges	53
Vegetation Cover and Patterns	13	Land Form and Topography	54
Water Presence and Patterns	19	Plant Cover	55
Land Use Patterns	24	Water Elements	56
Landscape Inventories	29	Focal Attractions—Local Features	57
Landscape Continuity	31	Landscape Setting	59
Scale	33	Scale	61
Boundaries and Edges	34	Boundaries and Edges	61
Land Form and Topography	35	Land Form and Topography	62
Plant Cover	36	Focal Attractions and Local Features	63
Water—River Drainages	37	Water Features and Elements	63
Focal Attractions—Local Features	40	Plant Cover	64
Landscape Province	43	Appendix	65
Scale	45	A. Maps and High Altitude Imagery	65
Boundaries and Edges	45	B. Visual Landscape Terminology	78
Land Form and Topography	45	C. Criteria for Recording Ground	
Plant Cover	46	Reconnaissance	82
Water—River Segments and Subdrainages ...	48	Literature Cited	83
Focal Attractions—Local Features	49		

Pacific Southwest Forest and Range Experiment Station
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IN BRIEF . . .

Litton, R. Burton, Jr., and Robert J. Tetlow

1978. **A landscape inventory framework: scenic analyses of the Northern Great Plains.** Res. Paper PSW-135, 83 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Retrieval Terms: scenic analysis; landscape inventories; Northern Great Plains.

Landscape inventories are a means of recording the scenic resource; they provide information needed for judging landscape values and predicting visual impacts. The main goal of this study has been to develop a set of related landscape inventories to fit a variety of scales, for application to uses ranging from broad area planning to small area design and management.

Research support came from SEAM (Surface Environment and Mining, Billings, Montana), and the Northern Great Plains was the case study area. Where coal is a major resource, there are concurrent problems of visual impact, landscape rehabilitation, and scenic conservation, all relating to mining activity. Adequate landscape inventory methods are thus a necessary start for conservation of landscape quality.

This study is based upon three elements:

1. A review of existing landscape inventory methods, concepts, and vocabulary—including relationships to physiographic classification systems.

2. An evaluation of high-altitude imagery, conventional air stereo photography, and topographic maps assembled for the study area.

3. Field sampling of typical landscape elements in the area, using ground and low-level air reconnaissance photography, along with sketches and field notes.

For each of the existing landscape inventory methods included, we examined scale of application, purpose served, and vocabulary used. As our inventory methods were evolved, we noted applicable vocabulary or concepts of existing methods, which are discussed in the text. Sum-

mary outlines of existing inventories are also given in the Appendix.

High-altitude imagery (ERTS, LANDSAT) samples of the Northern Great Plains were assembled for interpretation in scales from 1:1,000,000 to 1:125,000 in black-and-white, color, and infrared color. Topographic maps of similar scales (and down to 1:24,000 and smaller) matched the coverage, along with samples of NASA and conventional air stereo photography. The imagery and maps are judged as useful in landscape inventory work but need to be supported with the more tangible evidence that is familiar to us from ground and low-level air experience. Characteristics of the imagery and maps are interpreted in the Appendix.

Ground and low-level air reconnaissance, through some 8,000 miles of travel, sampled the landscape seen in the four-state area of Montana, Wyoming, North and South Dakota. Black-and-white and color photographs, along with sketches, represent the places and relationships observed—these images and the field notes are all keyed to topographic maps (1:250,000). The four basic elements contained in the field records document (1) land form characteristics, (2) vegetation cover and patterns, (3) water and its patterns, (4) land use patterns. The visual sampling accomplished in field reconnaissance became the tangible evidence upon which the landscape inventory method is based.

The landscape inventory method presented is a conceptual framework composed of four hierarchical parts: the Landscape Continuity, the Landscape Province, the Landscape Unit, and the

Landscape Setting. In descending order of scale, these designations apply to a range of characteristics, from the broad and general to the local and specific. In the presentation of the method, related terminology and concepts found in other landscape inventories studied are reviewed. Scale, boundaries and edges, land forms, patterns of vegetation and water, and prominent local features are identified at each level, with the help of photography, maps, and sketches.

The Landscape Continuity is the continuous and extensive landscape typical of a broad geographical region. As represented by the Northern Great Plains, it is placid, lacking in extreme visual contrasts. Its scale is large—about 235,000 square miles. Sheer mountains or level plains may form its boundaries, which typify the Continuity in being sometimes striking, sometimes imperceptible. Plant cover forms consistent patterns of grassland and riparian vegetation. Broad river drainages are the major water features. Prominent features are primarily objects on the horizon, such as contrasting land forms or groups of trees.

The Landscape Province, a regional-scale landscape, is a part of the Continuity, and yet in contrast to it. Its scale is variable; there are six examples within the Northern Great Plains Continuity. Boundaries may be sharply defined or gradual; land forms may reflect geologic formations or erosional development. Plant cover responds to the characteristics of the Province, as do water ex-

pressions and local features. Provinces in the Northern Great Plains include segments of one or more rivers or major streams, and local features such as the Missouri Buttes in the Black Hills Landscape Province.

The Landscape Unit is unified by enclosure. Though smaller in scale than the Province, its actual size varies. Unit boundaries are often spectacular, a primary source of scenic interest. Land forms notable in Units within the Northern Great Plains are the badlands associated with certain rivers. Plant cover and water within the Unit are more significant in their small-scale values—such as the quality of aspens framing a lake view. Focal areas within a Unit are of special importance because the visual impact of degradation is most obvious there.

The Landscape Setting is the indefinite area of landscape associated with a scenic feature of particular visual importance. It is frequently a designated area for management—a park, monument, or other protected unit. Devils Tower National Monument is an example. It includes an area of about 15 square miles; its boundaries are determined by the visual sphere of influence radiating from the land form—a conspicuous volcanic neck—which is its main feature. Plant cover may in itself form a Landscape setting, as when a small forest is ecologically related to a particular soil formation. Water features may enhance a Setting or be a main feature of it.

The landscape exists in several conceptual and interacting forms. It is an image in the viewer's eye. It is an idea in the mind, a memory, a feeling in the gut. It is a physical set of elements visible in space. This study concentrates upon the physical and visual elements and their compositional arrangements.

Visual landscape inventories are an expression of the currently widespread attempt to document the scenic resource. The way the landscape looks at a given time represents base line information to be used in judging landscape quality, in predicting the visual impact of proposed changes, and in determining the need for modification of proposals. There is only limited agreement, however, as to the physical elements and relationships that make up the visual resource. Inventory criteria, forms, and methods of recording vary accordingly. It is a time of empiricism.

The central and major goal of this study has been to develop an integrated set of visual landscape inventories, each representing a different hierarchical level. Existing inventories, products of individuals or agencies, generally relate to specific problems and scales of land planning or design. One example is the North Atlantic regional water resources study of the visual and cultural environment (Res., Plan., and Design Assoc. 1967), which is based on regional landscapes of

contiguous eastern states, a long time span, and broad land use planning problems. Another, the U.S. Forest Service's "visual management system" (1974b), addresses wildlands at the intermediate scale of a National Forest (or units thereof), emphasizing forest and resource management within an indefinite but apparently short time span. Litton's *Forest Landscape Description and Inventories* (1968), which the present study extends, suggests intensive landscape management, with application to localized landscapes at particular times. Except in limited and specialized applications (such as Litton and others 1974), there has been no integration of different scales of visual inventories within the single conceptual framework proposed here.

Through the sponsorship of SEAM (Surface Environment and Mining) we chose the Northern Great Plains, within the states of North and South Dakota, Montana, and Wyoming, as a case study area. Here there is a high potential for environmental impact relating to surface mining, especially of coal—a resource of vast proportions in the area. Planning for resource use, predicting visual impacts, developing methods for landscape rehabilitation where mining disturbances have occurred, and general maintenance of landscape quality—are all vital to conservation of the regional scenic resource. The development of

adequate visual landscape inventories for an area such as the Northern Great Plains must be the beginning of the conservation effort.

In the course of developing the integrated landscape inventories, we also attempted to review and develop landscape terminology for use at different scales, and to suggest relationships of our inventories to other scales of land inventory systems, such as those proposed by Fenneman (1931) and Wertz and Arnold (1972).

Our study is based on three elements:

1. A review of existing landscape inventory methods, concepts, and vocabulary
2. An evaluation of high-altitude imagery, including conventional air stereo photography, assembled for the study area
3. Field sampling of typical landscape elements in the area, using both ground and low-level air reconnaissance and photography

Eleven different landscape inventory studies have been examined. These either represent methods of analysis based on actual observation of the visual resource, or accept the concept of a visual landscape resource. The studies overlap to some degree. We did not examine landscape analyses based on physiography, soils, and vegetation; although these studies have important links to scenic analyses, they are essentially ecological rather than esthetic (see Hirvonen 1976).

For each inventory method, we determined (1) scale of application (breadth of land area embraced); (2) purpose served; and (3) vocabulary used. Some of the studies examined include assessment or evaluative procedures meant to serve application. Though useful, none go far to resolve the classic problem of weighing landscape quality. We have not attempted, either in appraising other studies or in pursuing our own, to consider techniques of quantitative assessment of landscape quality. Landscape evaluation must be considered a subject of continuing, long-term research. Review of existing inventory methods has provided guidance for the selection of landscape elements to be adapted for our use in proposed procedures. Additionally, the various scales of existing individual inventories have been helpful in development of our hierarchical inventory system.

For the evaluation of high-altitude imagery, we assembled imagery for photo interpretation in scales from 1:1,000,000 to 1:125,000, in black and white, color and infrared color. We assembled topographic maps (1:1,000,000 to 1:24,000 and smaller) to match the coverage, as well as samples

of conventional air stereo photography (1:52,000 and 1:30,000). We compared the merits of different kinds and scales of available imagery and maps, and identified elements possibly related to different inventory scales and their appropriate content. We concluded that high-altitude imagery alone does not provide the tangibility of elements needed for inventory of the landscape resource. Topographic maps, though also inadequate in this way, are a source of landscape information we seem to have previously ignored.

Field reconnaissance was conducted in the four-state area—Montana and Wyoming east of the Rocky Mountains and North and South Dakota west of the Missouri River. In the course of approximately 6,000 miles of road travel, we documented landscape elements with many color and black-and-white photos, and with field sketches and notes, all coordinated to 1:250,000 topographic maps. Additionally, we took low-level air photos in color and black and white—in 2,000 miles of air travel in eastern Montana, northern Wyoming, and western North Dakota. We believe that ground or low-level air reconnaissance and photography are an essential part of landscape inventories; for these there can be no substitute. Here they represent a direct sampling technique to assure that the case study area has been comprehensively examined as landscape. Maps and high-altitude imagery alone cannot provide this.

In this report of our study, the field work is first reviewed, as represented by selected sketches and photography. This is the primary source of our tangible, visual evidence of the Northern Great Plains landscape resource. Second, our conceptual framework for landscape inventories is presented in four parts: (1) the Landscape Continuity, (2) the Landscape Province, (3) the Landscape Unit, and (4) the Landscape Setting. The order of the parts corresponds to their scale, from the broad and general to the local and specific. Within each part, relations to terminology and land classification in other studies are mentioned. Selected photography and sketches for each part illustrate typical features as seen at the appropriate scale. In Appendix A, samples of high-altitude imagery and topographic maps are given, with comments on their usefulness in the development of landscape inventories. In Appendix B, terms presently in use in visual landscape analyses and inventories are given as abstracts from selected references. These serve to suggest current differences in research directions and opinions.

FIELD OBSERVATIONS

This study rests upon the premise that the visual characteristics of the landscape and their relationships are the raw material from which landscape resource inventories may be developed. Therefore field observations and records of the landscape of the study area, both from the air and from the ground, were essential. Field work was also needed to identify relationships—both similarities and differences—between the divisions of the region established by physiographers (Fenneman 1931, Hunt 1967, Thornbury 1965) and the divisions to be established for our study, which concentrates on the scenic resource. Our analysis of collected data—photography, field sketches, and notes—has been a primary means of developing the inventory procedures described in this paper. No visual analysis can be realistic without field work.

The study area, the Northern Great Plains, is defined by Fenneman (1931) as the Northern sections of the Great Plains province (*fig. 1*). It includes the eastern parts of Wyoming, and Montana, extending into Canada, and the western halves of North and South Dakota. It is bounded on the west by the Middle and Northern sections of the Rocky Mountains province, and on the east by the Western Lake section of the Central Lowlands province. To the south, there is a gradual transition to the High Plains section.

The air observations made in this study included both high-level and low-level imagery. High-level imagery for the satellite ERTS (now LANDSAT) and the space platform SKYLAB were secured from the EROS (Earth Resources Observation System) Data Center of the U.S. Geological Survey. (This imagery is illustrated and discussed in Appendix A.) Low-level air reconnaissance with 35-mm photography was made across southeast Montana and into west central North Dakota on June 9 and 10, 1974. Flight elevation was maintained between 500 and 2000 feet relative to ground level, so that most photographs could be taken at 1200 to 1500 feet above ground surface. Approximately, the center line of the air route (*fig. 2*) was 450 miles long, bearing North 70° East, beginning from Silver Gate, Montana, passing through Custer National Monument and Medora, North Dakota, and ending at Stanton on the Missouri River. Because the coverage was made in two 1-day loops out of Billings, Montana, actual travel was about 2000 air miles.

In principle, the air observation represents a transect across the Northern Great Plains. It begins on the west with the steep mountain margin of the Middle Rocky Mountains and touches the north opening of the Big Horn Basin. It ends on the east, at the Missouri River, where the Great Plains meet the Western Lake section of the Central Lowlands (*fig. 1*). Sampling from the air served as a preview for later ground-level observations.

Ground reconnaissance was made from July 17 to August 15, 1974, by automobile in the four States of the study area. A series of loops (*fig. 2*), covering about 6,000 miles of travel on both major and minor roads, allowed visual sampling of the broad characteristics of the Northern Great Plains physiographic sections and their boundaries. In addition, because visual landscape inventories need to make tangible the specific resource manipulations that have occurred in specific places, through showing the diversity of the landscape, we made ground observations of subordinate elements (physiographic units) within the Northern Great Plains.

To sample the landscape diversity of the region, the routing was planned to cover (1) land form characteristics, (2) vegetation cover and patterns, (3) water presence and patterns—such as river landscapes with their floodplain woodlands and badlands, and lake areas, and (4) land use patterns—that is, manmade changes. Visual scenic analyses are developed by documentation of these four areas of concern, which are fundamental to both air and ground observations, and may be linked to other studies in various disciplines—studies valuable in land use planning and resource management. Thus the detailed discussion which follows is organized around these topics, and they are also emphasized in the description of the various levels of the landscape inventory itself.

The ground reconnaissance was recorded through field sketches as well as photographs. (Detailed criteria for such records are given in Appendix C.) Together, field sketching and photography provide landscape information unavailable through either medium alone. The field sketch can abstract from the complexity of the landscape, simplifying the impression that a photo usually gives. A sketch is most apt to portray relationships of strong contrast—characteristic silhou-

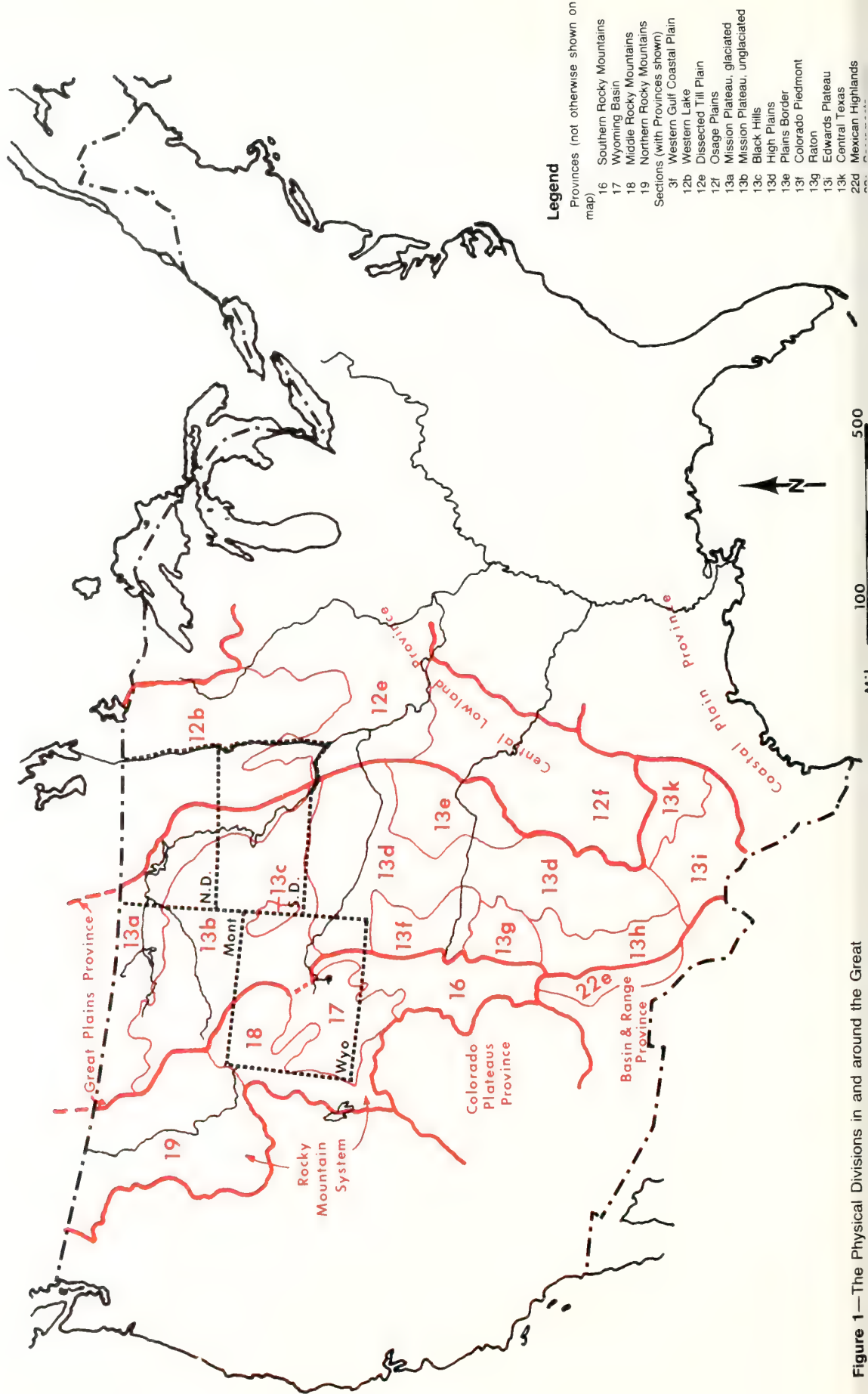


Figure 1—The Physical Divisions in and around the Great

ettes and slopes of land forms, edges between land surfaces and vegetation or water. A sketch can also express the essence of a place under conditions that are adverse to good photography; problems of flat or dim light, haze, rainy weather, or midday sun are minimized. The possibility of distortion exists in sketches as well as in photographs, but the complete concentration upon the landscape that is required in field sketching tends to improve both observation and documentation.

In the discussion which follows, both low-level air views and ground observations are presented, and some differences between them as to value for

particular purposes are pointed out. In general, the conditions responsible for these differences are (a) the distances and areas seen, as determined by the relative height of the eye; (b) the relative size or scale of viewed elements; (c) relative contrasts among landscape elements, such as forms and spaces and color values; (d) air clarity; and (e) illumination and sun angle.

As an overview of a large area or region, low-level air observation and photography seem superior to ground observation. Visibility at sea, which extends to the horizon, resembles that of flat terrain conforming to the curvature of the

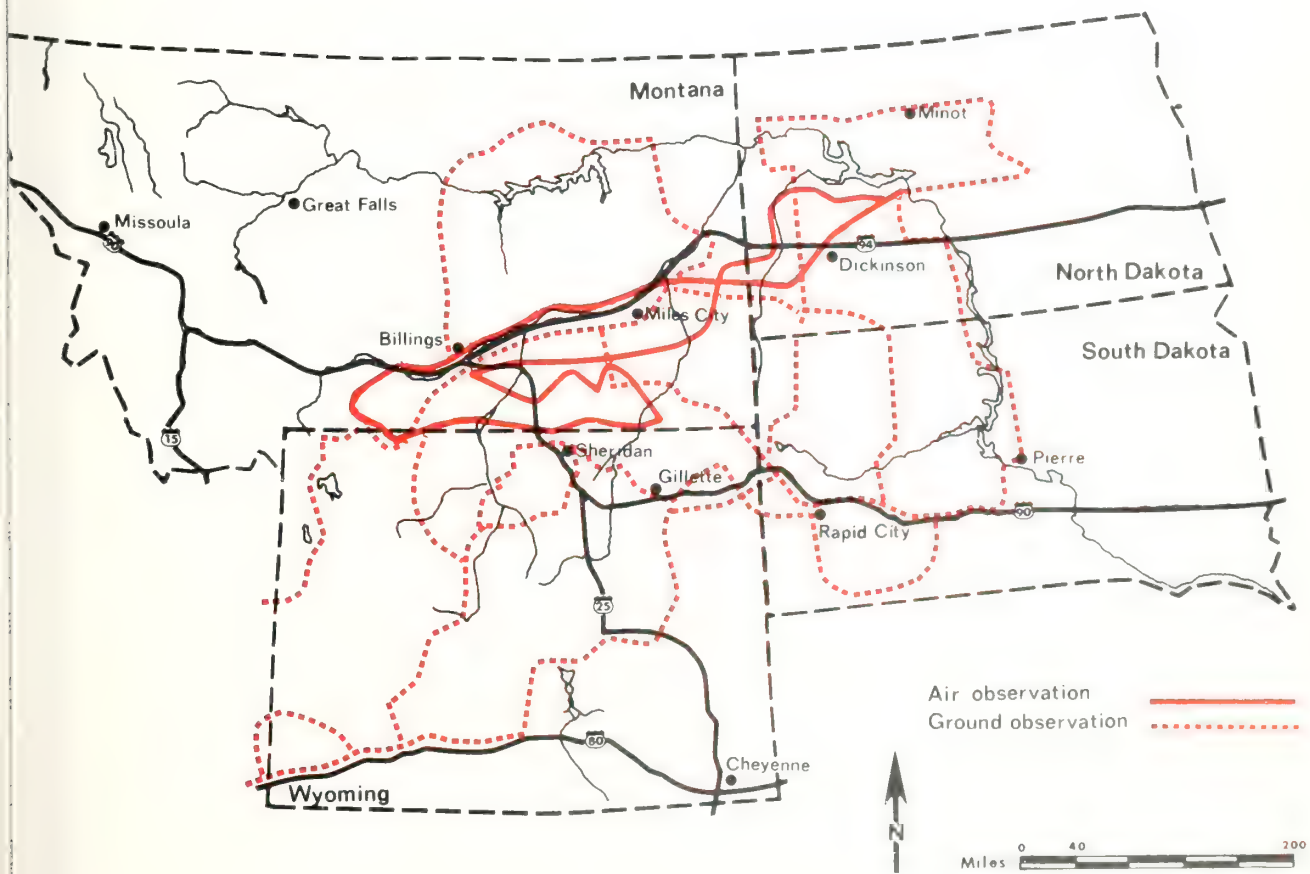


Figure 2—Air and ground observation routes are indicated on a base showing major numbered highways and major rivers

earth. From a 5½-foot normal eye height, the horizon is 3 miles distant; it is 51 miles distant from a height of 1500 feet. A significant effect of higher elevation observation is the approach to full planimetric view, as opposed to perspective foreshortening at ground level. The plan view tends to be two-dimensional, however, losing the three-dimensional form associated with the ground view. Skylines seen from the air, because they are more distant than those from the ground, are diminished in image size and also possibly degraded if air clarity is poor. Most land form silhouettes are seen from the air against a terrain background, so that visual contrast is reduced.

In this flat country, comparing what may be seen at ground level with a map indicates that a surprisingly small area is actually visible. Detail and the close-in landscape tend to dominate unless higher terrain offers elevated observer positions which give us more extended scenes. A real ad-

vantage of air viewing is its comprehensiveness. From the air, detection of homogeneous landscape areas and the margins between areas of contrasting landscape is easier; so also is determination of the extent and junctions of different vegetation types or land use patterns. Freedom of movement in the air is another advantage, allowing changes in orientation for superior observation or photography. The speed of air coverage is not only efficient—it also aids in making comparisons over a brief time span. Ground viewing tends to be discontinuous because it depends on road patterns. Roads also limit choices of observation points and orientations. Nonetheless, ground observation does represent our normal perception, providing reality and detail not to be expected from any other viewpoint. A combination of air and ground observation provides different kinds of landscape inventory information, not available from either means alone.



Air and ground views of similar subjects reveal marked differences. The air view is extensive, shows surroundings and junction between agricultural pattern and badlands, and suggests the whole planimetric layout of strip crop agriculture (near Amidon, Little Missouri River, North Dakota). The ground view is limited and detailed; surroundings are not apparent and the geometric pattern is distorted in perspective relationship to surface undulations (north of Glendive, Yellowstone River, Montana).

Land Form Characteristics

Land form characteristics are a primary means of differentiating one landscape area from another. In particular, the freedom of movement provided by air observation makes it easy to see the extent of homogeneous landscapes—those which show a visual unity because of repeated similar forms. Edges, or the margins between areas with dissimilarities, are equally discernible, as are boundary zones of transition which show gradual change. Viewing from the air confirms that the physiographic provinces of the Middle Rocky Mountains and the Northern Great Plains abut one another sharply (fig. 3). The junction constitutes a distinctive edge, an area of concentrated visual interest: the steep mountain slopes of high relative relief (thousands of feet), capped by angular skylines, meet a transitional strip of hills and hogbacks with modest relative relief (hundreds of feet), moderate slopes, and predominantly rounded skylines. Then the essential flatness of the Northern Great Plains begins.

In general, land form characteristics provide in visual inventories the primary means of describing generalized form characteristics according to slope, scale, and silhouette; they identify individual or grouped forms which dominate an area or have a sphere of visual influence; they define areas according to the repetition of visually similar forms (homogeneous landscapes); and they identify boundaries and transition zones which mark the junctions between visually contrasting areas.

In this section, certain conspicuous aspects of land forms seen from air and ground are illustrated. Silhouette views of individual land form features can be significant from the roadway but can be quite lost in air views. We are apt to see only a segment of a larger land form—or a small part of repeated land forms—in ground views. From the air, it is easier to see that repeated similar forms can define areas of homogeneous landscape character. Also, from above, junctions between dissimilar landscapes become clear, the appreciation of scale is heightened, and there is more complete visibility of large, dominating land forms.

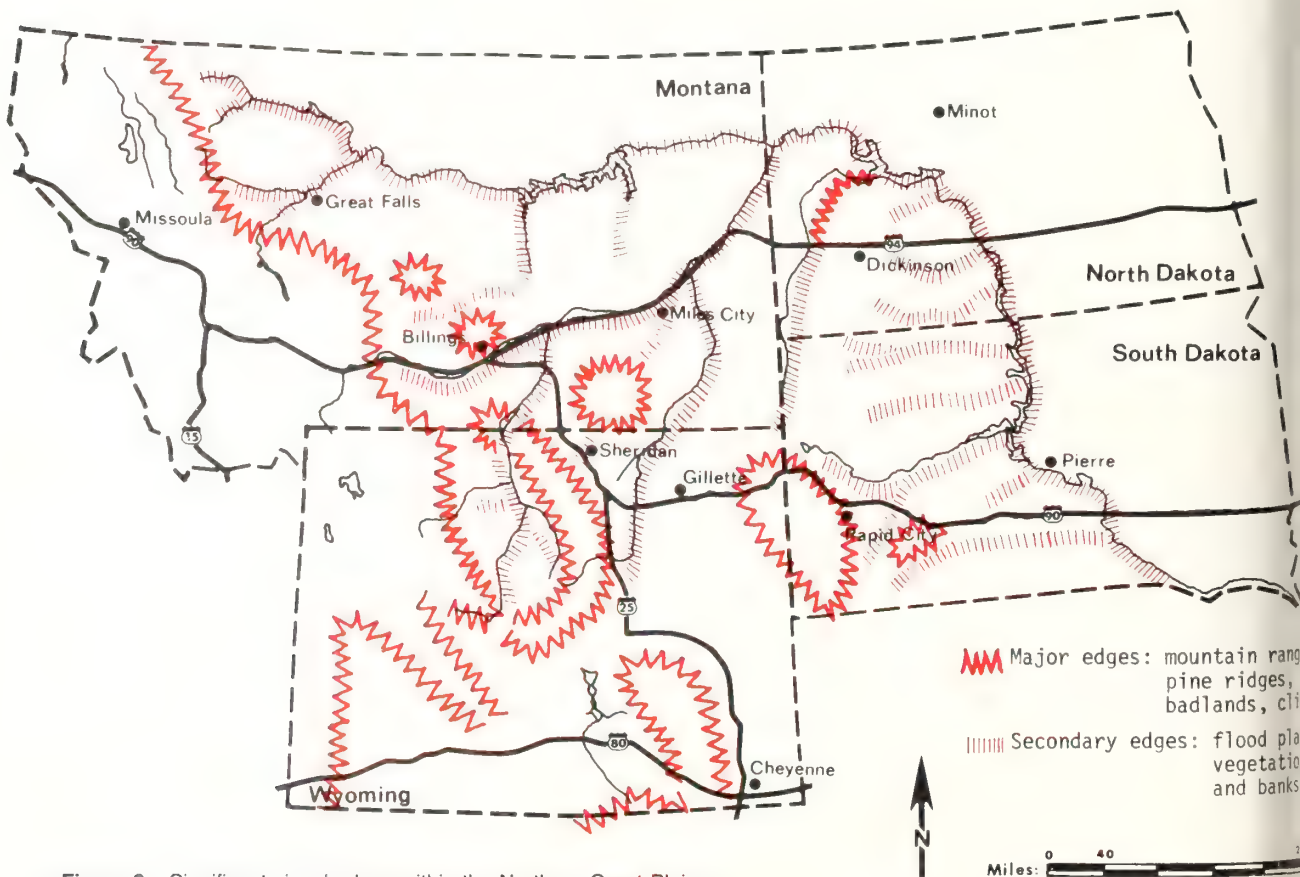


Figure 3—Significant visual edges within the Northern Great Plains.



Top: Angular mountain landforms with their conspicuous silhouettes are typical of the Middle Rockies, forming one distinctive boundary for the Northern Great Plains. (Pilot and Index Peaks, N. Absaroka Range, Wyo.)

Bottom: Transitional landforms with relatively low relief and rounded ridges against the Middle Rocky Mountains are another visual edge of the Northern Great Plains. (Beehive, Mont., Beartooth Mountains in background.)



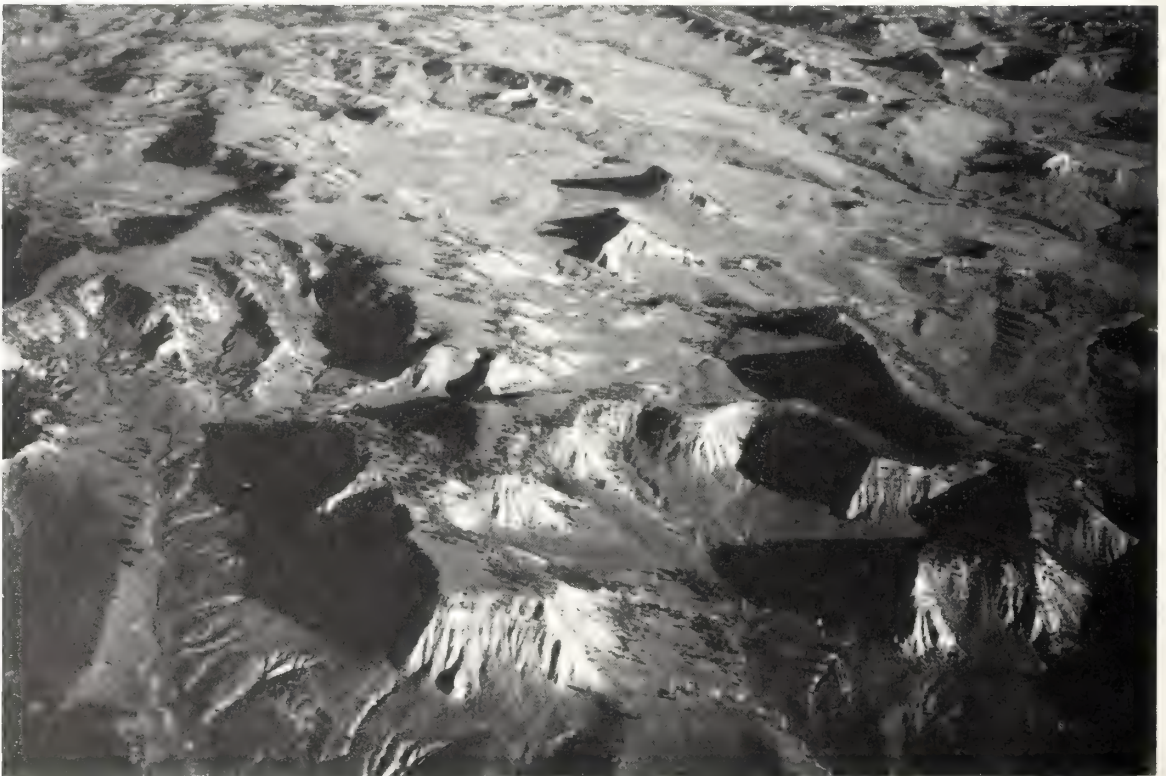
Top: Landform silhouettes are obvious expressions of the Northern Great Plains, but are also locally dominant in the landscape. (West side, Pryor Mountains, Mont.)

Bottom: Hogbacks are usual in the transition edge of visually perceived form in the landscape. These truncated cones, buttes of modest size, are associated with Northern Great Plains badlands. (Little Powder River, Mont.)



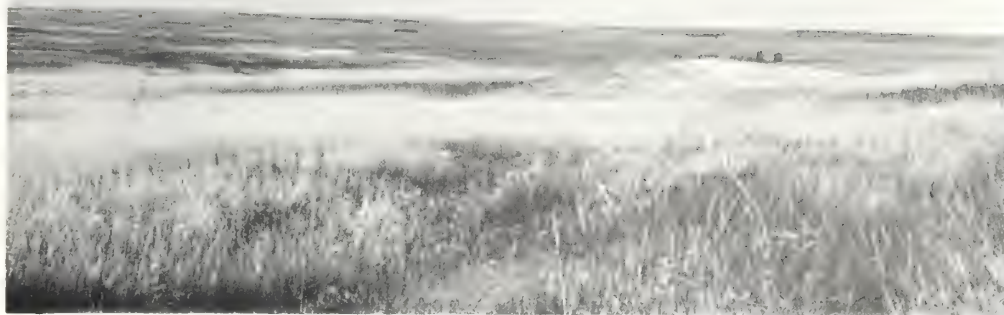
Top: Grouped granite needles become a landscape feature by their ridge skyline position and contrasts of form and color against pine forest. (Custer State Park, Black Hills, S. Dak.)

Bottom: An individual land form of distinctive silhouette and massive scale, with patterned surface of varied strata and pine-scrub cover, is a landscape feature of a different kind. (Tensleep Canyon entry, Big Horn Mountains, Wyo.)



Top: The visual edge between dissimilar landforms—flat agricultural fields and badlands—is clearly seen in this comprehensive air view. (Near Lake Sakakawea, Little Missouri River Badlands, N. Dak.)

Bottom: Repeated landforms with similar yet varied form make a homogeneous landscape. The air view reveals the extent and limits of this homogeneity. (Near Tongue River, south of Miles City, Mont.)



The predominant expression of the Northern Great Plains landscape is flatness, gentle undulations of surface with great extent. Its scale is grand, seen in both a vast sky and boundless horizontal land plane. (Near Badlands National Monument, S. Dak.)

Vegetation Cover and Patterns

Vegetation cover and patterns are of considerably greater consequence to analysis of the visual landscape than they are to physiographic analysis: physiographic divisions depend fundamentally on the effects of geological structure and process. There may be overlapping, however. The Black Hills, which form a physiographic section by virtue of their structure (*fig. 1*), derive their name from the apparent blackness of ponderosa pine. The darkness of color is obvious because the hills are thrust up through a surrounding plain of light grass. In many parts of the country, both ground and air views reveal visual contrasts between forest cover and terrain. On a smaller scale, plant cover is an intimate overlay of land form, usually reflecting patterns traceable to microclimate, exposures, drainages, and compatible soils. Low-level air views provide a superior means of identifying the extent of a dominating cover—especially grassland or forest; of investigating the

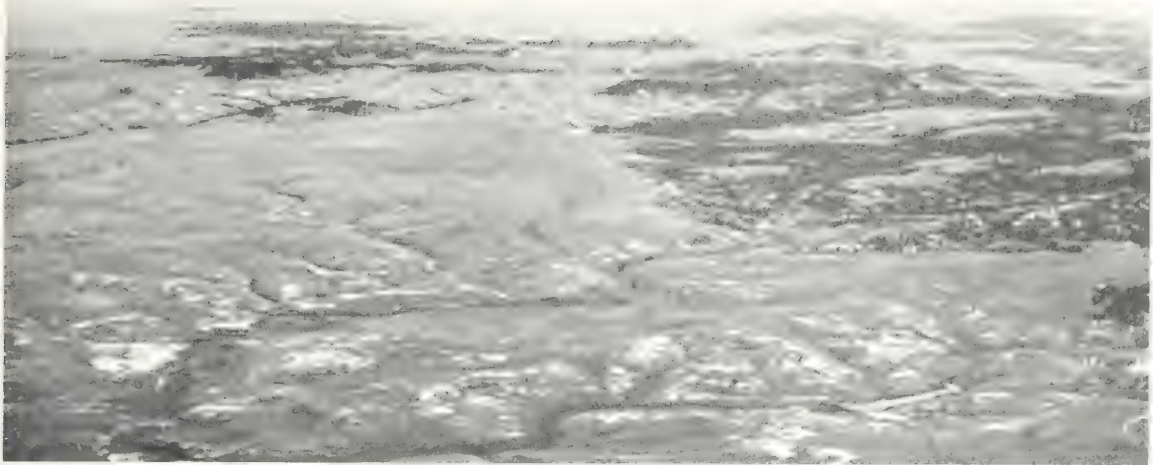
margins between areas with contrasting plant covers—these junctions being special sources of visual interest; of identifying upland vegetation patterns that are based on land form relationships; and of identifying the extent of riparian vegetation and patterns, including their relations to streams, to basic channel spaces, and to upland vegetation.

In this section, visual relationships of vegetation cover and patterns are illustrated. The presence of two distinctly different vegetation types—especially grassland and forest—is visually significant in any view of the landscape. From the ground we are apt to see bits and pieces of margins between forest and grassland, but from the air we can appreciate that whole areas of similar character may be dominated by one kind of plant cover. Riparian vegetation, seen from ground level, suggests the presence of water, but the connections between water bodies and adjacent vegetation become entirely visible from the air. Also, from the air we have a more complete sense of how vegetation patterns tie to the patterns of topographic form.



Top: Grassland is the dominating vegetation of the Northern Great Plains, extensive from horizon to horizon, seldom interrupted. (Keyhole Reservoir, Wyo.)

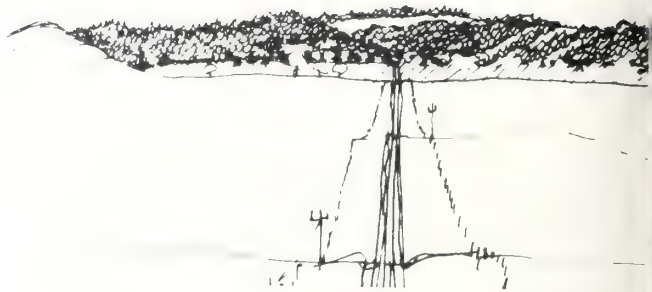
Bottom: Ponderosa pine is locally dominant and makes upland enclaves in contrasting seas of grass. (Black Hills National Forest, S. Dak.)



Top: The margin between forest and grass cover is a conspicuous line between two dissimilar landscapes. (East of Miles City near Powder River, Mont.)

Bottom: Light grassland is subordinate in proportion here to dark pine forest. (Otter Creek area and Tongue River, Mont.)

Top: The road sustains focal attention on the grassland-conifer edge at middle distance and the upland forest beyond. (Pine Ridge, Black Hills, Wyo.)



Middle: Masses of contrasting plant covers, with their sharply defined edges, create a landscape mosaic. (Deer Creek, Glendive, Mont.)



Bottom: Contrasting plant covers mark a flatland edge and provide a subtle introduction to uplands. (Belle Fourche River, near Devils Tower, Wyo.)





Top: Fingers of upland vegetation follow minor drainages and are seen against riparian woodland below. (Theodore Roosevelt National Memorial Park, North Unit, Little Missouri River, N. Dak.)

Bottom: Cottonwoods occupy the interior flats of river loops, forming a recurrent pattern. (Near Medora, Little Missouri River, N. Dak.)



Top: Three other vegetation types seen from a moderate distance—light grass-scrub and dark conifers on higher land, brighter riparian woods below. (Charles M. Russell National Wildlife Range, Missouri River, Mont.)

Bottom: Contrasts seen at close range: three life forms and colors—gray scrub, bright aspen, dark pine. (Black Hills, S. Dak.)

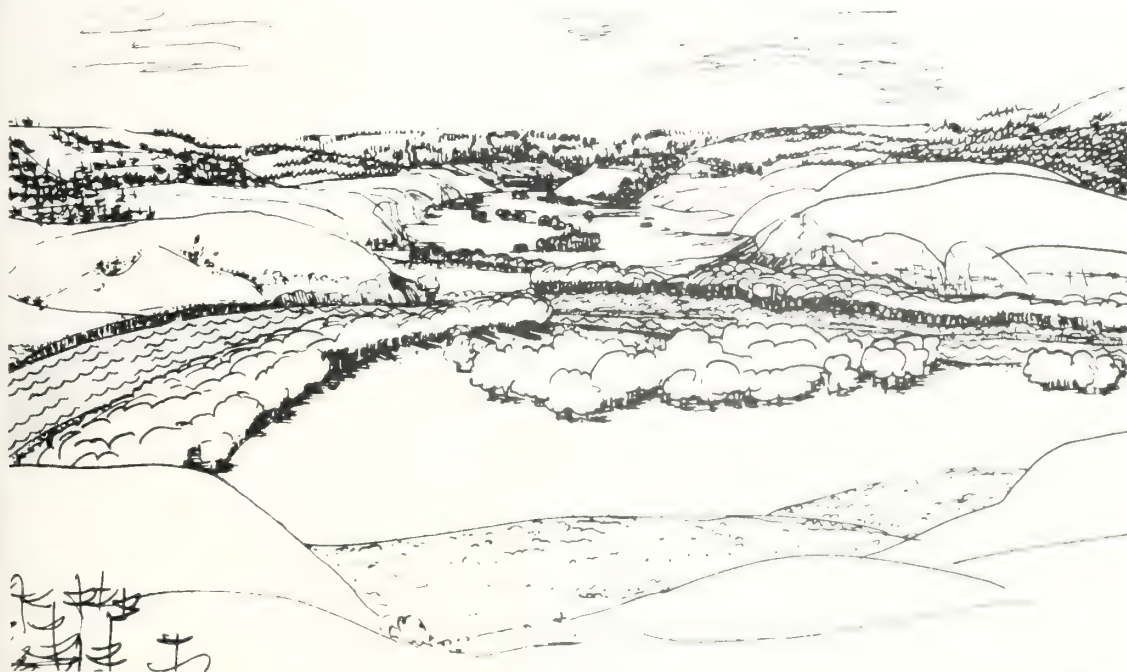
Water Presence and Patterns

Water presence and patterns become special sources of visual amenity within the Northern Great Plains because it is a relatively dry country. In more moist regions, the presence of water is not associated with particularly marked visual changes. In dry areas, however, visual contrasts exist throughout the year between riparian vegetation and the vegetation of higher, drier land. Color differences are always a major factor in visual contrasts and especially so within the Northern Great Plains. During much of the year the lighter, bright greens of the riparian zone are seen against surfaces that are gray or buff. Typically the Northern Great Plains water expression is the meandering stream with concentric bands of associated vegetation—characteristics more readily seen from the air than from the ground. Clear water is unusual; coloration by silt is usual. Apart from impounded segments of streams, lakes are essentially nonexistent—this is the major difference between the Great Plains and the lake-dominated landscape of the Central Lowlands east of the Missouri River (*fig. 1*). Badlands of the Northern Great Plains combine with streams so as to form areas of special visual interest—these are the typical areas of this region which are designated as one kind of Landscape Unit in our system. Other relationships provide significant visual

contrasts between land form and stream patterns; rivers may be deeply entrenched—as the Big Horn River is through the Big Horn Mountains—or steep bluffs may flank a river—as the Yellowstone River bluffs do near Pompeys Pillar. Stream paths in these flat plains are usually meander or braid patterns.

Low-level air observation is superior to ground observation for detecting entrenched river pattern and extent; identifying extent of bluff or areas of topographic breaks associated with streams; identifying badlands areas and their limits in association with rivers; identifying flatland stream patterns, associated riparian vegetation, and relationships to upland vegetation; and identifying the presence and abundance of lakes and stream impoundments.

From the ground, as from the air, the presence of water and its patterns are prime sources of scenic potential in most landscapes, and particularly in the Northern Great Plains. In flat country viewed from the ground, the presence of water is more likely to be implied by contrasts of riparian vegetation than to be actually visible. Ground viewing also seeks to document incised river patterns, for example, but has limited potential from the lower level; other water features (such as white water) observable from the air can be recorded from the ground as well, though with less comprehensiveness.



The alcove flat of a meandering side stream, with riparian vegetation, enters the larger flood plain space of the Missouri River. (Armells Creek at the Missouri River, Mont.).



Top: Deeply incised river meanders with continuous bluffs make a distinctive visual unit, conspicuous from the air. (Big Horn River, Yellowtail Reservoir, Wyo.)

Bottom: Bluff, stream, and vegetation relationships form a distinctive landscape with the river as the central feature. (Theodore Roosevelt National Memorial Park, North Unit, Little Missouri River, N. Dak.)



Top: A meandering stream typical of the Northern Great Plains is joined by a riparian woodland strip and badlands edge. (Powder River, Mont.)

Bottom: A water impoundment occupies the breadth of a former flood plain, and contrasts with the narrow outfall stream. (East end, Tongue River Reservoir, Mont.)



Top: Stream defiles are the major breaks seen in these repetitive undulate plains and ridges; water is absent or invisible. (Missouri River slope, near Mobridge, S. Dak.)

Bottom: A sinuous stream pattern is seen in relation to a riparian flat and adjacent bluff enclosure. (Near Killdeer, Little Missouri River, N. Dak.)



Top: A pond rests within the enclosure of small rounded hills and reflects them. (East side of Little Rocky Mountains, Mont.)

Bottom: Live streams and related wetland cottonwoods are two relatively rare landscape elements of the Northern Great Plains. (Cannonball River, N. Dak.)

Land Use Patterns

Land use patterns within the Northern Great Plains are relatively limited in both extent and visual impact. Urbanization is apparent primarily in small compact towns, which seem further diminished because of the large scale of the surrounding landscape. Agricultural use patterns are very extensive, but the typical grain crop strips alternating with fallow strips are dominant from the air rather than the ground. Because agricultural patterns occur on flatter or leveled parts of an already flat landscape, ground perspective tends to hide them. Roads which cling close to the general surface in this flat or undulate country similarly are inconspicuous on the ground except for their characteristically long tangents. Road grid patterns become obvious from the air.

Strip mining does appear conspicuous from the air; the scale of digging areas is massive even in the expansiveness of their surroundings. The area disrupted by mining is relatively concentrated, so that it is a focus of attention. The light color of spoil piles normally contrasts with darker undisturbed surfaces. Spoil piles are seen as geometric three-dimensional patterns from the air, whereas their ground views, especially in the Dakotas, are of steeply angular and pointed manmade forms.

Reclamation regrading subdues visual contrast through slope flattening and ridge rounding, but does not affect surface color significantly. Undoubtedly the most conspicuous visual indication of coal mining is the coal-burning power or gasification plant, with tall stack and great smoke plume—somber domination of a flat landscape and vast skyscape.

Low-level air observation in relation to land use effects provides an excellent means of identifying organization of land use patterns, edges between different land uses, junctions between land use areas (and their patterns) and the natural landscape, and areal extent or scale of land use.

Illustrated here are samples of the more conspicuous land use patterns encountered in the Northern Great Plains. The ground view of a village is apt to be dominated by a few taller elements—trees and grain elevator typically; from the air it is the geometric pattern and overall block of streets, buildings, and trees. Agricultural patterns are those of the farmstead combined with tree plantations and parallel grain strips. The massive geometric forms of coal strip mines are apparent from the air but less so from the ground. Obvious ground signs of mining are those of peaked, sometimes light-colored, spoil piles, smoke stacks, and the visual impact of smoke in the atmosphere.



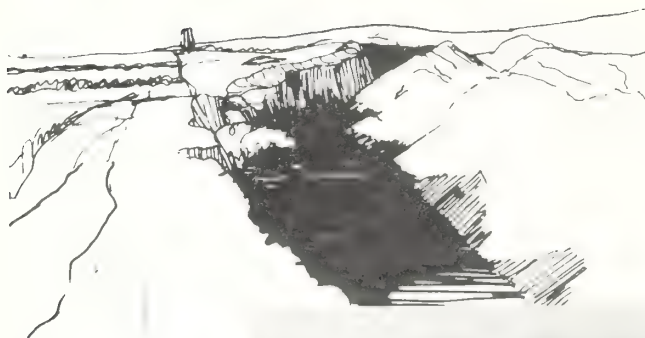
A typical entry impression of a Great Plains village is made by vertical forms of trees and grain elevators. (Clearmont, Mont.)



Top left: The urban land use pattern seen from the air is the geometry shared by buildings, roads and trees. (Hazen, N. Dak.)

Top right: Farmstead groups, abandoned or occupied, form another pattern element of agricultural land use—vertical exclamation points widely spaced on a flat landscape. (Highland Flat, Bill, Wyo.)

Bottom: The predominant expression of the Northern Great Plains landscape is flatness, reinforced by horizontal strips of agricultural land use. The village makes a contrasting vertical block. (Amidon, N. Dak.)



Top: A close-in sketch of strip mining in flatlands shows the linear cavity with coal bed exposed and adjacent spoil pile prior to reclamation. (Near Beulah, N. Dak.)

Middle: Visual impacts are combined here in a flat landscape: the horizontal coal stripping pit and overburden piles, and the vertical power plants with their smoke plumes. (Stanton, N. Dak.)

Bottom: Coal stripping with geometric linear impacts, and water impoundment conforming to topographic contours are two kinds of large-scale land use patterns. (Tongue River Reservoir, Decker, Mont.)



Top: Strip mine spoil piles, before reclamation grading, make strong pyramidal silhouettes upon a horizontal landscape. (Stanton, N. Dak.)

Bottom: Low rounded profile of land form reconstruction matches surroundings in this spoil pile reclamation. (Stanton, N. Dak.)

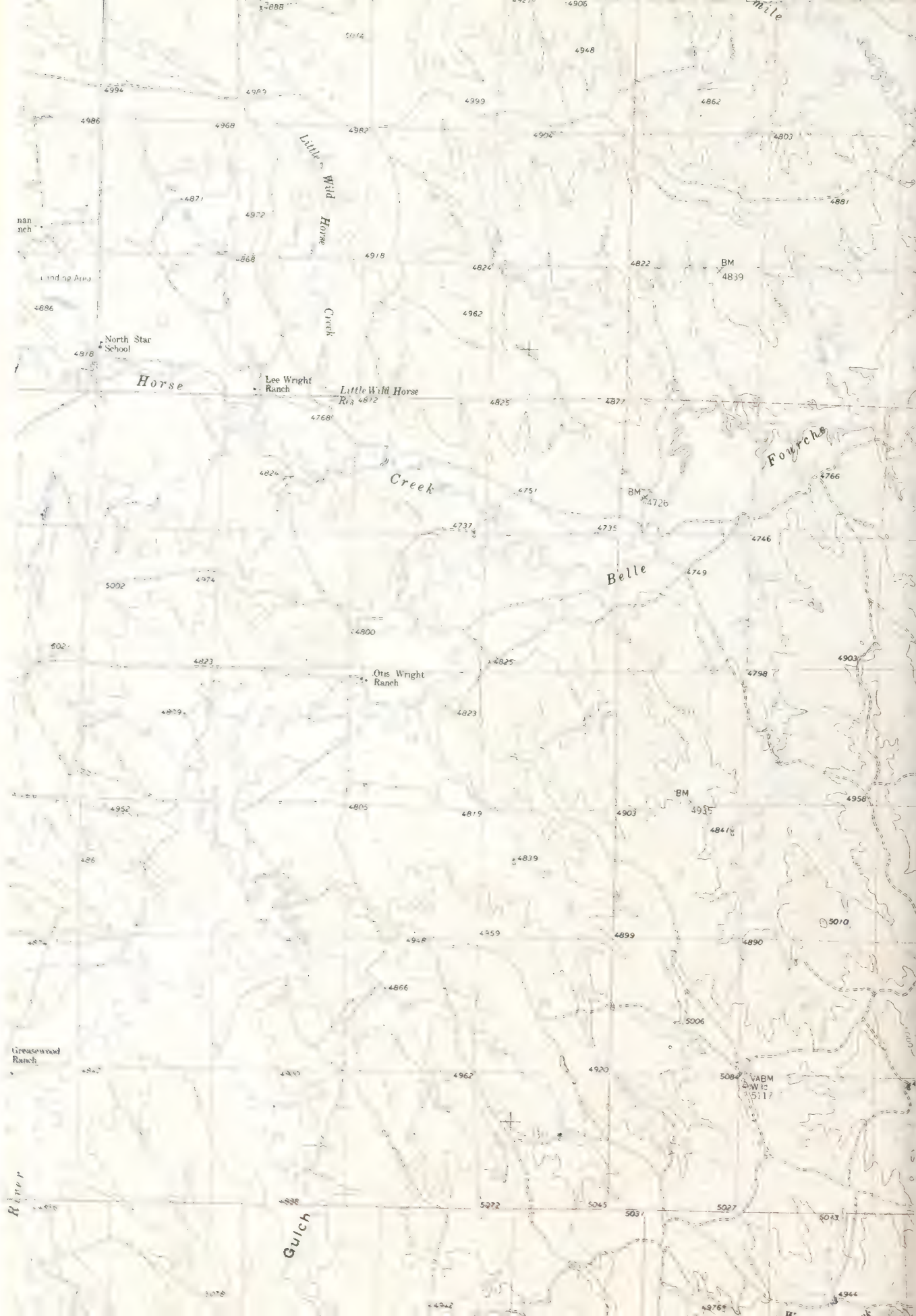
LANDSCAPE INVENTORIES

The conceptual framework of this landscape inventory, developed in the context of the Northern Great Plains, is described in four parts: the Landscape Continuity, the Landscape Province, the Landscape Unit, and the Landscape Setting. The discussion in each part begins with a definition, including references to related terminology and land classification in other studies. Then, the particular level is described as to scale, boundaries and edges, land form and topography, plant cover, water (as appropriate to the scale), and focal attractions or local features.

The sketches and photographs accompanying the discussion of each inventory level serve to illustrate the points made in the text, in a broad

and general way. They are arranged sequentially, but a particular photograph or sketch may clarify features or principles discussed under various headings. Illustrations in the preceding section, Field Observations, will also help to provide the tangibility necessary to better understanding of the inventory method.

The map (*fig. 4*) provides a good general view of the whole inventory framework. It shows how the different elements of the inventory relate to one another in scale and location. The base map shows river watersheds to suggest a sense of scale and place that is based upon natural subdivisions of the landscape.



LANDSCAPE CONTINUITY



An extensive landscape with repetitious, undulating land forms and flat horizon typifies the Northern Great Plains Continuity (Gillette, Wyo.)

The Landscape Continuity is the continuous and extensive landscape typical of a broad geographical region. The term "Continuity" suggests a visual flow of repeated relationships in similar land forms, vegetation cover and patterns, and water elements. The basic homogeneity of a region is implied, rather than mere repeated similarities of a smaller area, and the term applies to any kind of extensive landscape. Accordingly, some Continuities are placid, perhaps monotonous, in that they lack marked contrasts; examples are the undulate grasslands of the Northern Great Plains or the sagebrush steppe of Oregon and Idaho. Other Continuities are vivid in their display of differences; an example is the angular mountain landscape of the Middle Rocky Mountains, with its strong variations. Whatever the attributes, they create, by their visual impact, a regional identity. Of course, even within a broad landscape that shows an apparent consistency or homogeneity, there are variations. Yet the continuum—the Continuity—is extensive enough and apparent enough so that breaks in character are relatively small in area. The Continuity is a visual matrix that is not obliterated by such pockets of internal change.

The Northern Great Plains Continuity is a placid one. Extreme visual contrasts typical of scenic landmarks are largely absent. Simple and similar land forms, recurrent over broad grassland expanses, produce an impression of monotony. Yet small islands and other areas of modest change may be encountered within the continuum.

According to its elements and their relationships, landscapes may be called scenic, ordinary, or perhaps degraded. Seasonal changes, among various influences, can bring greater or less distinction to any landscape, however. The landscape of the Continuity—when a norm is represented—provides a reference level for comparisons. From the generalized visual characteristics of a regionally consistent landscape, it should be possible to determine changes in quality that represent either greater scenic contrast or deterioration and degradation.

The Landscape Continuity, represented by the Northern Great Plains as an example, is intermediate in scale between the physiographic province and the section or subprovince (Wertz and Arnold 1972, p. 4–5). Thousands of square miles are included in this example, and delineation may be made on maps of 1:1,000,000 scale and consid-

erably smaller. Other Continuities may be of much less extent.

We identify the following physiographic sections of Fenneman (1931) as making up the Northern Great Plains Landscape Continuity: Missouri Plateau (glaciated), Missouri Plateau (unglaciated), and the Big Horn and Wyoming Basins (parts of the Middle Rocky Mountains). (See *figures 1 and 4.*) Although the Black Hills Section is included, we give it a separate identity. This Continuity can also be identified with the Upper Missouri Basin Broken Lands and the Big Horn and Wyoming Basins of Hammond (1964).

The term "Landscape Continuity" has been chosen because it suggests repeated visual characteristics that are common and typical for a broad and continuous area. It is not a static image so much as a dynamic impression obtained in traveling for days at a time. Burke and others (1968) have used the term "characteristic landscape" to mean the typical landscape which "... occurs most of the time—the average condition ..." as seen along a roadway. No particular scale is implied, but the examples emphasize the roadside of the High Plains and adjacent Rocky Mountains. Burke's emphasis is upon evaluation—making comparisons with the average condition. The Forest Service landscape management procedures (U.S. Forest Serv. 1974b) define "character type" as the landscape typical of any single physiographic section according to Fenneman's (1931) classification. These same procedures define "characteristic landscape" as a directly viewed sample of a character type. Thornbury (1965, p. 8) makes use of Malott's definition of a physiographic (geomorphic) unit as one with "characteristic topographic elements" throughout, and as contrasting with other units displaying other land form characteristics. This usage restricts the meaning to topographic elements—one part only of the visible landscape. So a number of different meanings are carried by landscapes designated as "characteristic," but all such meanings help to define the idea of the Landscape Continuity.

In *Study of the Visual and Cultural Environment* (Res. Plan and Design Assoc. 1967) a set of "Landscape Series" are defined, classifying divisions of the landscape according to "... repetition of a dominant land form over a large area." Two series, "undulating land" and "flat land" (or a combination "Compound Series") would apparently apply to the Northern Great Plains.



Familiar geometry and structures of a small town provide a scale comparison to the extensive surrounding landscape. (Hazen, N. Dak.)

Scale

Landscape Continuities are the broader regional expanse—they are not the immediate, personal and local landscapes of scenic “places,” such as Kevin Lynch (1960, p. 119) describes. Their scale, in consequence, is large. In the Northern Great Plains, actual land forms and vegetation patterns are small, but their repetition produces largeness in scale. Breaks are infrequent. Continuities are usually so expansive that their dimensions are not easily visualized in the abstract. The Minnesota Lakes region, the Texas rangelands, or the Northern Great Plains are collectively expansive enough to lack tangible scale. Most travelers never touch all the borders of these areas, never reach its extremities. The landscape is thus measured by travel time rather than by surface dimensions.

The Northern Great Plains Continuity covers

an area of approximately 235,000 square miles—about 350 by 550 miles—within the following nominal boundaries: (1) the Missouri River to the north and east, (2) the Nibora and White Rivers to the south, and (3) the Rocky Mountains edge in the west (*fig. 4*). An even larger area is logically included within this particular Continuity. It consists of the Big Horn and Wyoming Basins and the glaciated and unglaciated physiographic sections of the Missouri Plateau. The northern limits apparently lie in Canada at about the latitude of Great Slave Lake (Thornbury 1965, p. 287).

In an aircraft, Continuities are rapidly traversed. One grasps the relative proportions of regional areas, their beginnings and endings. But detachment from landmarks, internal elements, and edges creates an abstract experience entirely different from that of the surface traveler. The greater the altitude and speed, the greater the detachment.



The western boundary of the Continuity is abrupt against the Central Rocky Mountains edge, but there is a transition zone of lower hills and hogbacks. (Aerial view, Beehive, Mont.; Beartooth Mountains in background)

Boundaries and Edges

Appreciation of extent depends on seeing the edges of an area. A Continuity is a consistent landscape through which one travels, and the traveler is in an area where edges are beyond visual limits. One may circle a lake, for example, to appreciate its boundaries at first hand, but large areas may appear endless because their extent and the difficulty of access prevent circumnavigation.

Edges experienced at the point of entry into a Continuity may erroneously be thought typical. The size of the Continuity often precludes uniformity of boundaries, however. Sheer mountains may lie along one edge and nearly imperceptible land form differences mark another—this is true

of the Northern Great Plains. In such great expanses, edges, when encountered, may seem remarkably dramatic because of contrast. The flank of the Middle Rocky Mountain west of Billings, Montana, makes a vivid blockage in the Great Plains landscape. By comparison, the margins between the Northern Great Plains and the adjacent High Plains or the Central Lowlands are soft transition zones—inconspicuous to the eye. When the Continuity has edges or boundaries that are particularly vivid, relative to the characteristic features on its surface, those landscape areas adjacent to the edge assume a special character. Distinct edges suggest sources of higher scenic interest. This can happen without changing the nature or the quality of the visual characteristics of the greater part of the Continuity.

Land Form and Topography

Surface form is ordinarily consistent throughout the Continuity. Over so great an extent, minor or local interruptions in this surface character are likely. They are attributable to erosion of stream systems, variations in soil and the geologic base, or geologic disturbances—upheavals, faulting, or folds. Because these are logical variants explained by underlying natural forces, their visual or scenic presence has meaning; they do not seem disruptive or detractive. They are local centers of interest within the Continuity. If they stand out sufficiently because of variation in visual form and size, they may be recognized as discrete subunits. Landscape Provinces and Landscape Units, in this inventory procedure, are so recognized within the Continuity.

Typical land forms of the Northern Great Plains Continuity are long, gentle slopes with flattened, rounded, or peaked tops, which emerge from an

undulate surface. Low relative relief is the common denominator. Examination of randomly chosen square-mile sample areas on 7½-minute topographic maps indicate relative relief of less than 100 feet to about 200 feet; in cross-section, some are symmetrical, others asymmetrical. River troughs are another definite form: flat-bottomed defiles with moderately sloping sides—or bluff banks on cutting sides—are depressed below the horizon plane. Spaced 25 to 50 miles or more apart, the flood troughs seem less common than they actually are because roads do not often intersect them. Badlands topography, though common enough within this Continuity, is sufficiently contrasting in visual form to be classified into sub-areas, the Landscape Units. Mountain peak forms—such as the Black Hills or Big Snowy Mountains, outliers of the Rocky Mountains—or forested upland areas are also separated from the Continuity because of obvious differences; these are Landscape Provinces.



Repeated similar and undulating grass-clad land forms provide the impression of a homogeneous landscape. (Near South Fork of Moreau River, S. Dak.)

Plant Cover

In the Continuity, plant cover is more important for the consistency of the patterns developed than for the continuous presence of a particular plant species. The pattern of repetition provides the characteristic identity, but variations in pattern occur, reflecting favorable or marginal cultural conditions. In the Continuity, it is normal to expect such differences; their frequency depends on latitude, soil, exposure, available water, and other

conditions which limit plant location and diversity of type.

In the Northern Great Plains Continuity, grasslands constitute a major visual characteristic—a fine-textured, light-colored blanket which echoes the gentle terrain below it. Within the grassland, however, are at least three different grassland types, as well as grassland-sage combinations. All are similar in appearance. In visual terms, the grassland predominates, but to those with the requisite knowledge and a discerning eye, the subtle differences are revealed, and underlying cultural variations can be inferred.



Top: Grain crops, suggestive of natural grasslands, are a light-colored blanket echoing the gentle terrain. (Near Pierre, S. Dak.).



Bottom: Grassland and grain crops are the dominant vegetation of the Continuity, accompanied by typical contrasts of riparian tree lines and groves. (Near Medora, N. Dak.).

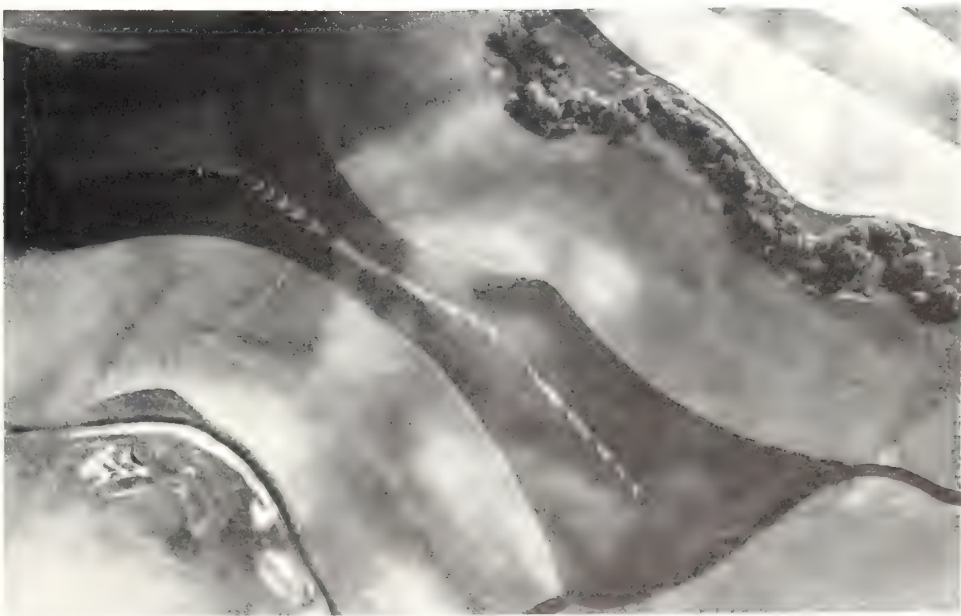
A major theme variant of the plant pattern is found in the characteristic riparian linearities. Pockets, lines, concentrations, and scatters of trees and low plants follow meandering water-courses and drainages through much of the area. Visual contrast—hence distinction—comes from the darker trees and associated plants that stand out against the lighter grassland. Tree lines trace out invisible streams. The amount of tree cover is small compared to grass, and frequently the tree patterns of lines and patches lie low below the crests of terrain.

Water—River Drainages

The presence of water is a conspicuous visual element in any landscape. It is, additionally, a major force contributing to the formation of identifiable visual elements, whether at the broad scale of the Landscape Continuity or at the much smaller scale of the Landscape Province. Terrain gradient, precipitation, and water volume, rock and soil types, and riparian vegetation all contribute to the landscape seen as directly related to water and its action.



Streams typical of the Northern Plains meander across the flats, flanked by cottonwoods in the riparian zone. (Aerial view, O'Fallon, Mont.)



Visual mosaics result from the juxtaposition of farm crop patterns and riparian lines of creek vegetation, but are conspicuous only from the air. (Aerial view, Sentinel Butte, Medora, N.D.)

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+48°

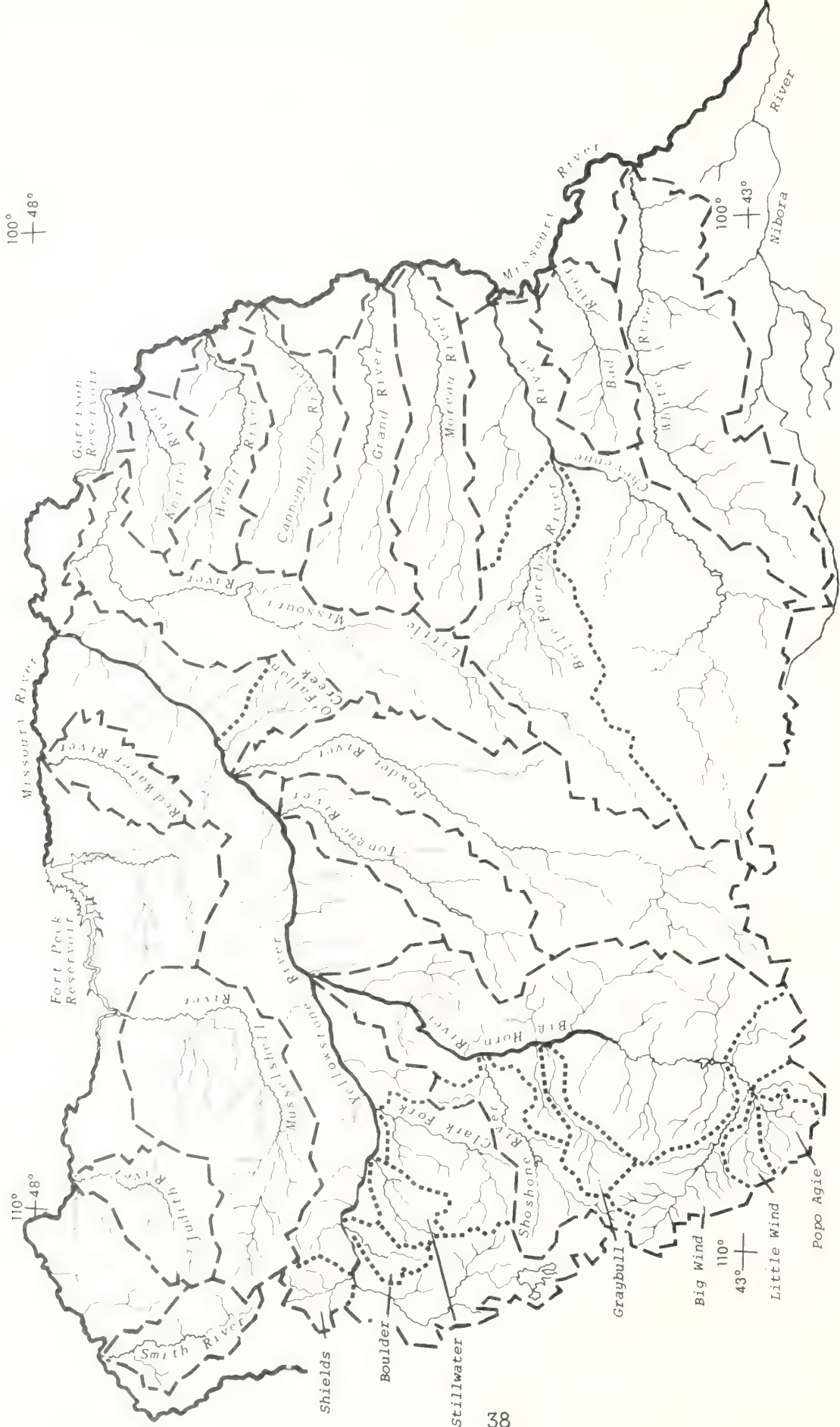


Figure 5—River watersheds of the Northern Great Plains and adjacent Rocky Mountains.

--- River watershed boundary
..... Tributary river watershed

Table 1—Rivers of the Northern Great Plains and Middle Rocky Mountains, draining north and east into the Missouri River, between 48° N. 110° W. and 44° N. 99° W.

River ¹	Watershed area	Watershed orientation	Alignment length ²
	Sq. miles	Azimuth	Miles
Smith	2,100	330°	85
Judith	2,900	030°	95
Musselshell	9,275	060°	205
Red Water	2,050	030°	80
Yellowstone	21,775	350°-060°	540
Shields	850	160°	35
Boulder	650	020°	45
Stillwater	1,025	050°	55
Clark Fork	2,975	030°	95
Big Horn	16,850	020°	220
Shoshone	2,975	070°	120
Graybull	1,125	060°	85
Big Wind	2,350	120°	120
Little Wind	1,200	090°	45
Popo Agie	825	050°	40
Tongue	5,425	030°	160
Powder	13,550	025°	320
O'Fallon Cr.	1,475	320°	70
Little Missouri	6,100	020°	295
Knife	2,375	070°	85
Heart	3,325	090°	135
annonball	4,325	070°	145
Grand	5,350	090°	170
Moreau	5,575	080°	185
Heyenne	17,725	070°	350
Belle Fourche	6,950	030°-070°	230
Mad	3,150	070°	100
White	9,775	080°	260

Rivers in the Middle Rocky Mountains are shown in italic. Alignment length is generalized, omitting meanders; measurements made on 1:1,000,000-scale map for comparison only.

Rivers and their drainages are numerous within the Landscape Continuity. They tend to repeat similar visual relationships, although each river is an individual. The traveler, crossing or moving parallel to the rivers of the Northern Great Plains can expect repetitive elements, such as

1. Definite flood plain troughs depressed below general terrain level, usually deep enough to screen riparian woodlands from outside view
2. Trough edges, variable but predominantly of three types: gentle to moderate slopes, steep to nearly vertical bluffs, and badlands strips—riparian woods within the trough creating subordinate edges

3. Sinuous or meandering stream patterns with slow water—frequently silty.

The repetition of watershed orientations and streamflow from west to east of the eight rivers draining into the Missouri (from the Knife in the north and down to the White in the south) suggests similar visual characteristics (*fig. 5*). This particular set of similar orientations also indicates repeated and marked contrasts between north-face and south-face vegetation.

The scale of the Landscape Continuity is indicated clearly by its many rivers and river systems, which are best seen on a small-scale map (*fig. 5*). Within the Northern Great Plains Continuity, between latitudes 43° and 48°N, there are 15 rivers. These range from the Red Water, the smallest, to the Yellowstone, the largest (*table 1*), all draining into some 700 miles of the Missouri. The Yellowstone alone carries one third of the watershed runoff of this portion of the Landscape Continuity; 13 streams are tributary to it—8 within the Middle Rocky Mountains. At the scale of this Landscape Continuity, the number of creeks is legion—some, such as O'Fallon Creek, could be considered rivers.

Crop pattern of alternating fallow and planted strips gives visual emphasis of subtle land forms. (Dawson Co., 20 mi. north of Glendive, Mont.)





An isolated butte, distinguished by a dark skyline cap, is a local feature within the Continuity. (Harding Co., North Fork of the Moreau River, S. Dak.)

Focal Attractions—Local Features

Focal attractions are the landscape configurations commanding our attention and acting momentarily as visual anchors as we move through space. Gibson (1966, p. 197) indicates that for the observer in motion, objects appear to stream by in our visual field. In rapid forward motion, only the point of aim of sight remains sharp and relatively stable. Contrasting elements seen at greater distance also appear fixed. It is natural for

us to fix upon some distinctive element rather than gaze at blank or neutral areas. The number of such focal attractions to be seen in the landscape could provide an index of visual quality, either according to degrees of contrast encountered or frequency at which contrasting attractions occur within a broad landscape. Focal elements are conspicuous because of the way they are displayed; they may be more easily remembered for their contrast with their surroundings.

A focal landscape (Litton 1968, p. 32–35) is one which by form, or by the disposition of its ele-



Top: The road focuses attention ahead, singling out this combination of land form folds with tree patches as attractions within a broad, placid landscape. (Approaching Badlands National Monument, S. Dak.)



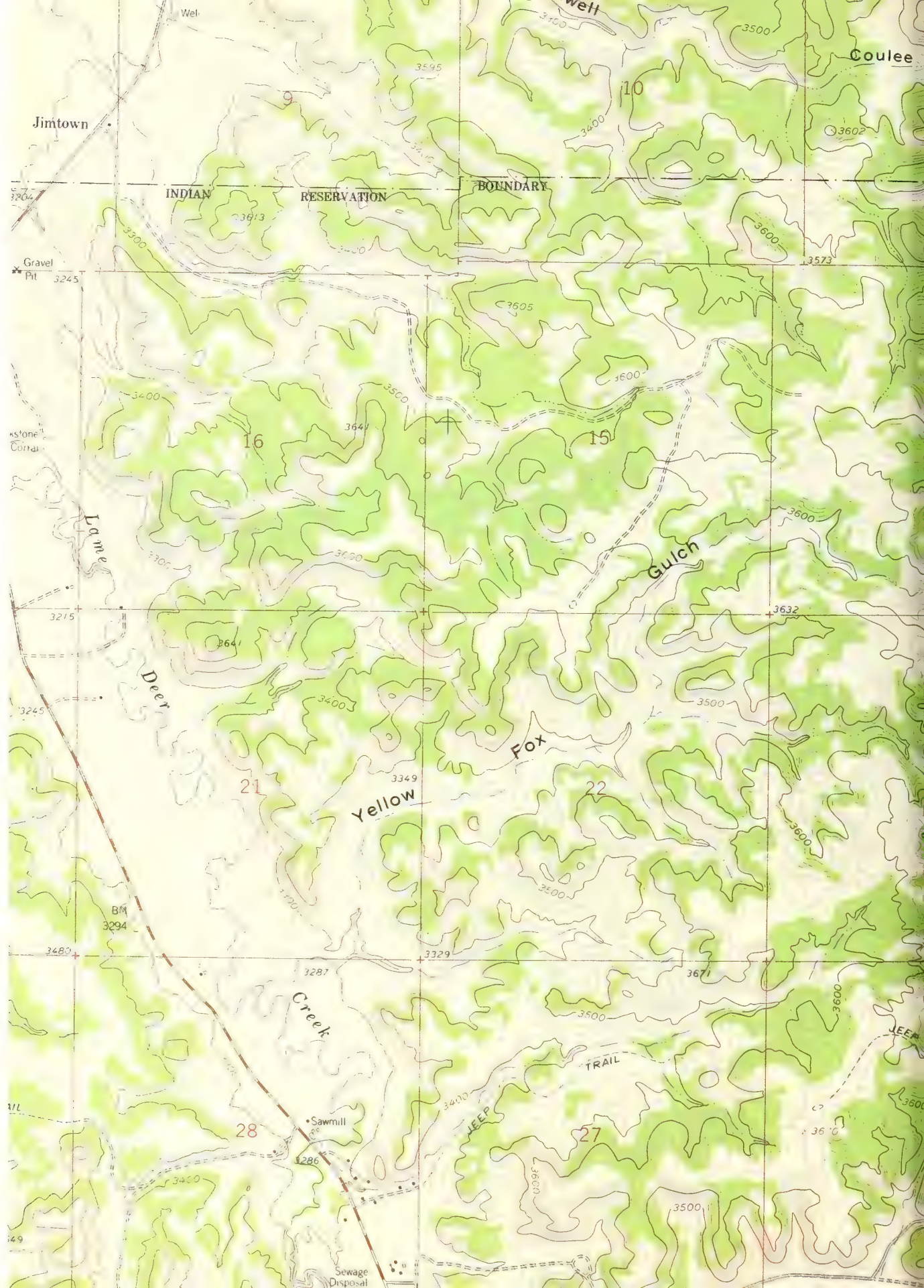
Bottom: Abrupt rock formation with "keyhole" at the skyline is a local feature. (Devils Gate, Sweetwater River, Wyo.)

ments, tends to force the observer's gaze along a given line or direction. In nature, the disposition of elements within streams and drainage defiles, together with the location of the observer, produces focal landscapes. Straight segments of roads leading toward the horizon also direct the observer's attention. The design of roads and overlooks can capitalize upon these particular characteristics.

Local features of the Continuity are primarily objects on the horizon, dominant, isolated, or contrasting land forms, or groups of trees (Litton 1968, p. 26-27). Some may be named, such as Hell's Half Acre, Wyoming, or Bear Butte, South

Dakota. The size of Continuities prevents dependence on any one of these; but the presence and repetition of contrasting small features provide interest and local identity. For open landscapes such as those typical of the Northern Great Plains, the focal aspects of roads or objects on the visible horizon predominate. A driver's attention is directed forward.

Landscape elements seen on an extension of forward view lines enjoy major advantage. Planning and design for scenic roads can take this into account. By this one means, at least, local landscape features of the Continuity can be significantly displayed.



LANDSCAPE PROVINCE



An area of repeated small, steep land forms with dominant pine cover stands out within the Continuity as a Landscape Province. (Colstrip, Mont.)

7.5-minute Quadrangle Segment: Jimtown, Montana.

The Landscape Province is a regional-scale landscape area with a combination of distinctive visual features which set it apart in its broad geographical setting. It is a part of the Continuity and yet in contrast to it. The visible differences that mark a Province may begin along a sharp line of demarcation or at least may occur within a narrow zone. Again, gradual blending of contrasting parts may create an almost imperceptible edge. The elements of a Province must be seen as contrasting with the broader landscape. The Province is identified by new surface groupings and land form configurations; they may be larger or smaller in scale, or markedly different in color impression. Another significant characteristic is a distinct change in vegetation type.

Uniqueness, frequently a characteristic of the Province, results from scenic variety in the generalized landscape; it offers relief or diversion to the traveler crossing large geographical areas. Yet, in the strict sense, a Province is not necessarily unique—its features may exist elsewhere in the Continuity. Thus, several Provinces may be similar in having steeper topography with higher relative relief than their surroundings. The Province has sufficient extent and visual unity to stand out clearly as an island within the Continuity (fig. 4). It is large enough to have within its boundaries a variety of its own in scenic landscape.

The Province characteristically has a name closely related to the landscape and its qualities. As well as serving for general reference and location, the name conveys something of the actual quality of a place. On the contrary, names of some broader divisions, such as the Rocky Mountains or the Mississippi Basin, evoke only generalized geographic images. The Province should be sufficiently vivid in character to warrant a name that suggests a fairly precise image of reality. The Black Hills and the Big Horn Mountains are Province names that evoke clear visual images.

We identify six Landscape Provinces as examples in the Northern Great Plains Continuity (fig. 4): The Black Hills, Big Horn Mountains, Tongue River Ponderosa Pine Uplands, Musselshell Ponderosa Pine Rise, Big Snowy Mountains, and Bearpaw Mountains.

In our visual inventory classification, the Landscape Province is a second-rank division, following after the Continuity. Similarly, in Fenneman's physiographic classification, the Province is a

second order designation, following after "major division." The Province is also defined as a biogeographic division of less rank than a region. Study of the Visual and Cultural Environment (Res. Plan. Design Assoc. 1967) does not designate hierarchical units, but it does classify divisions called "landscape series" based upon "repetition of a dominant land form over a large area." Such series as "mountain" or steep hill," for example, could be used as a means of identifying a Province. The Landscape Province is considered the most distinctive large subdivision within the broad, regional Continuity.

The Landscape Province is an area of high imageability. Lynch defines the term as "that quality in physical objects with high probability of evoking a strong image in any given observer. . . ."

The Surface Resources Work Group study (1973) does not develop any special terminology but rather depends upon generalized description or places recognized by name. "Scattered Ponderosa Pine Country" or "The Black Hills" indicates special areas which happen to coincide with the concept of the Landscape Province. In *Water and Landscape* (Litton and others 1974), certain concepts, and the criteria presented in defining the "landscape unit," can be used in identifying and analyzing the Landscape Province. The underlying theme in both applications is a repetitive consistency of visual landscape elements within discrete, distinctive subareas of a broader region.

The Landscape Province is related to the physiographic section or subprovince in scale (Wertz and Arnold 1972, p. 5). From hundreds to a few thousands of square miles may be included; delineation may be made on maps of 1:500,000 or 1:250,000 in scale. We show Fenneman's Black Hills physiographic section as a Landscape Province, but also identify several other Landscape Provinces (such as the Tongue River Ponderosa Pine Uplands and the Big Snowy Mountains) which, because of their character or size, are not differentiated as physiographic sections within the Northern Great Plains. Fenneman has referred to isolated mountains such as the Big Snowy Mountains as "exceptional features" seen as islands within the physiographic province or section. We also distinguish the Big Horn Mountains Landscape Province as a visual subdivision of the Middle Rocky Mountains physiographic province.

Scale

The Province has been defined as having a regional scale. The definition of “regional” must be reasonably flexible. The Province is seen as a recognizable island, seeming small in area when compared to the extensive Continuity in which it lies. It cannot be identified by any arbitrary measure of size, such as number of square miles, and representative Provinces may vary rather widely in area. Of the six Landscape Provinces of the Northern Great Plains shown in figure 4, the Black Hills covers slightly more than 5000 square miles and the Tongue River Ponderosa Pine Uplands about 4500; the Big Horn Mountains extends over some 4200 square miles; the Bearpaw Mountains covers about 1200 miles; and the Big Snowy Mountains and the Musselshell Ponderosa Rise cover about 900 square miles each.

A possibly useful unit of measure is the distance traversable within the scope of a day’s journey in a particular area. In large and open landscapes with scattered scenic elements, good roads, and gentle gradients, this measure would designate an extensive area. In hilly or mountainous country, rich in spatial details, water features, and terrain quality, much less ground could be covered in a day’s journey, and the unit would designate a shorter distance.

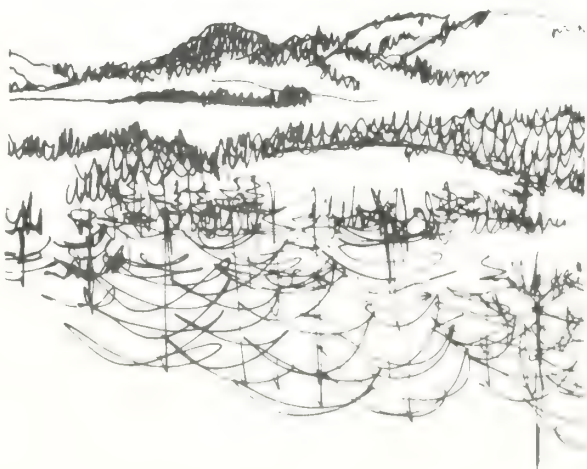
Boundaries and Edges

In visual terms, the edges or boundaries of the Province may be sharply defined or somewhat gradual. Topographic breaks, streams, and forest borders are typical edges, usually in combination. Vividly perceived Provinces, such as the Black Hills, tend to have abrupt edges as boundaries over a good portion of their perimeters. Too gentle a gradation weakens perception of area beginnings, with consequent diffusion of visual impact. When Province boundaries are vivid—perhaps topographically abrupt—rail, road, or trail entrances to interior areas are likely to occur through passes, gaps, or canyons. These are all landscape spaces that provide a sense of enclosure and lead to an interior landscape. Descent into the interior of a Province through such constrictions is likely to be a more visually revealing scenic experience than an ascent to a plateau, but either encounter is interesting for its contrast to a preceding journey.

Land Form and Topography

One of the simplest sources of the visual distinction of the Province is terrain—land forms markedly at variance with those of the surrounding Continuity. Normally, land forms are derived from basic geologic action in nature—vulcanism, uplift, folding or faulting. Erosional dynamics of water also create diverse local landscapes. The Province as situated within a Continuity of more ordinary landscape is usually distinguished by terrain forms that are of a differing geological formation that covers a limited area, or alternatively, is made or modified by erosion. The Black Hills Landscape Province is such an area—one of original uplift, now modified by erosion. It rises from the Great Plains plateau as a unified central mass, surrounded by sharp ridges and narrow circumferential valleys. Although water has softened much of this perimeter, a distinct elevational difference is visible from the surrounding area, and the traveler has a vivid sense of penetration through its boundaries to an interior of mountain peaks, deep valleys, and plateaus. These topographic distinctions are important to its character.

Steep hills of the Province and heavy pine cover are both different from characteristics of the Continuity. (Black Hills, S. Dak.)



By virtue of their scale, Provinces may include a considerable variety of terrain. Linear to peaked escarpments of sheer rock, steep interior peaks and glaciated valleys, plateaus, or ancient lake beds and glacial debris may all form part of a single Landscape Province.

The visual distinctions of steep slopes and land forms with high relative relief, in part typical of mountain scenery (Linton 1968), are found consistently within most of the Landscape Provinces identified. That is, steep landscape elements with relatively high relief are not absent from the surrounding Continuity; but there the concentration of such forms is less evident, and the elevational difference is smaller. Some examples may be cited, as evident in the 1:250,000-scale U.S. Army Topographic Maps:

- In the Black Hills, St. Elmo Peak is high (el. 7241) rising 2200 ft in 2½ miles, and 12 miles east the general level drops 3800 ft (el. 3400 ft).

- In the Big Horn Mountains, east and west edge scarps rise 2000 feet in 2 to 2½ miles, Cloud Peak (el. 13,175 ft) rises 3000 feet in 4 to 5 miles, and 24 miles east the general level drops 8000 feet (el. 4900 ft).

- In the Big Snowy Mountains, the relative relief of Great House Peak is 3700 feet in 7 miles.

- The Musselshell and Tongue River Landscape Provinces, though not mountainous and having less local relative difference in elevation (Musselshell: 1000 ft in 5 miles, Tongue River: 1500 feet in 2 miles), are nonetheless in marked contrast to the flatter surrounding Continuity.

Plant Cover

Plant cover in the Landscape Province is responsive to the special characteristics which set that terrain apart from the generalized landscape of the Continuity. Uplift for example, in creating the land mass of a Province, elevates ground level to an altitude which favors certain plants. Differences of substrata and rock types have an eventual impact on soil types, with corresponding plant response. The presence of high peaks and ridges brings climatic changes, with winter snow and other precipitation sufficient to make significant differences in the available supply of water. The net effect is that the Landscape Provinces of the Northern Great Plains are covered by dark forest growth, seen in distinct contrast to the light-colored grasslands of the Continuity. The “blackness” of the Black Hills’ ponderosa pine forest

This introductory view of a Landscape Province is enhanced by the sharp edge between flatland with grass, and hills with pine forest. (Pine Ridge, Black Hills, Wyo.)





Top: Nearly equal proportions of grass and trees establish a small scale pattern of contrasting vegetative covers. (Bear Lodge Mountains, Sundance, Wyo.)



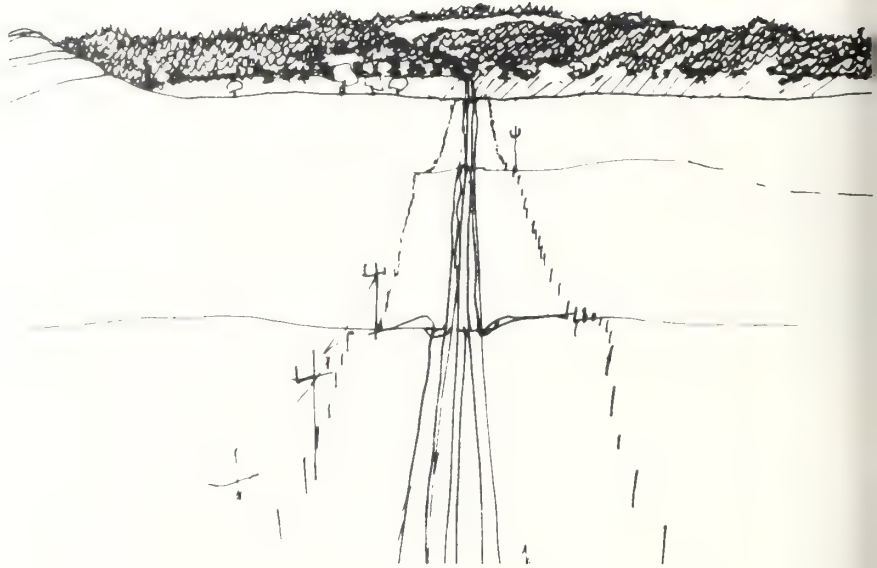
Bottom: Ponderosa pine forest creates an enclosure and gives focal emphasis to the roadway. (Vicinity of Badger Peak, North Cheyenne Indian Reservation, Mont.)

cover clearly illustrates such contrast. (In defining Landscape Provinces by areas of distinctive plant cover, the map and accompanying manual, *Potential Natural Vegetation* ..., Kuchler 1964, is a helpful reference.)

Vegetation patterns are varied within the Northern Great Plains Provinces, requiring description in visual terms rather than mere reference to plant cover. In the outer perimeter of the Black Hills, there is a pattern of ponderosa pine ridges enclosing "prairies"—grassland areas of relatively large size, from a few to tens of square miles in extent. Deeper into the interior, smaller grassland pockets replace the prairies, and pine forests are more continuous; some forest areas are

dominated by granite spires thrust up through them and are distinctive enough to be inventoried as Settings. In the Big Horn Mountain Province, there is a somewhat similar pattern of large prairies and forest, but the tree types are lodgepole pine and spruce-fir. In the Tongue River Ponderosa Pine Uplands Province, a two-part pattern is based on opposing exposures. A seemingly continuous ponderosa pine forest occupies gentle northerly slopes but is actually interrupted by steep, light-colored scarp formations facing south. Views north thus contrast sharply with those to the south. Plant cover patterns typical of the other Provinces can presumably be identified.

A straight road segment focuses upon the grassland-pine margin with dark forested hills above. (Black Hills, S. Dak.)



Water–River Segments and Subdrainages

The Province is large enough to include sizeable segments of one or more rivers or major streams, together with systems of creek tributaries, and usually lakes. The form of the Province may vary from a range of mountain peaks, whose drainage is multidirectional and characterized by lakes and small headwaters, to more low-lying terrain where parts of well-developed rivers make edges or are central, scenic attractions. Within the limits of the Province, water, with its commanding visual characteristics and relationships, is normally significant among the scenic resources.

The scale of the Province, like that of the Continuity, may best be judged through reference to a map (*fig. 4*) showing the parts of rivers and other streams that are included. Additional detail is needed, however. The U.S. Army Topographic Maps, 1:250,000 scale, show the following water elements within the sample Landscape Provinces of the Northern Great Plains:

1. In the Black Hills, the Belle Fourche and Cheyenne Rivers define a large part of the Province's north, south, and west edges. Only about a

third of the total length of the Belle Fourche and a seventh of the Cheyenne are included, along with a few of their tributary creeks. Within the Province are a very large number of creeks and some 60 small lakes—mostly manmade impoundments.

2. In the Big Snowy Mountains there are about 35 named creeks; Flatwillow Creek is the largest stream originating in this area.

3. Almost all of the north boundary of the Musselshell Province is defined by a quarter of the length of that river. About 15 named creeks either lie within this Province or originate within it, and there is one lake.

4. The Tongue River Ponderosa Pine Uplands is named for the river, about a third of which is contained within the Province. A small number of major creeks (Otter, Rosebud, Sarpy, Hanging Woman) are included, as well as about 95 other named minor creeks. The Tongue River reservoir is on the west edge of this Province.

5. In the Big Horn Mountains Province, there are headwaters of the Tongue and Powder Rivers and part of the Big Horn River, which slices through the Prior and Big Horn ranges. Within a 5-mile radius of Cloud Peak, there are more than 90 alpine lakes. More than 400 named creeks are estimated to be in the Province.



Top: Granite needles are another kind of local feature, grouped together and conspicuous on the ridge above a dark forest. (Custer State Park, Black Hills, S. Dak.)



Bottom: Lake impoundment with steep land and forest enclosure is a local feature of the Province. (Pactola Reservoir, Black Hills, S. Dak.)

Focal Attractions—Local Features

Initial distant aspects of a Province, seen as contour edges or general silhouettes, are themselves focal attractions when viewed from the surrounding Continuity. Within the highly varied Province, there are many land forms to be seen as local visual features: mountain and hill peaks and ridges, scarps and exposed intrusions, mesas, and valleys and canyons of different proportions. Water bodies and water displays are included (Litton and others 1974).

Focal views of landscapes, structured by roads, stream reaches, or converging narrow valleys,

particularly when directed to scenic features such as peaks, are especially apt to be vivid expressions. Individual and separate visual impressions of local features may be effectively drawn together within a Province through the linkage of a road. Within the Northern Great Plains Landscape Provinces, a few of the many local features to be identified are the Missouri Buttes and the Devils Tower in the Black Hills, and Bald Mountain or Leigh Creek in Tensleep Canyon inside the Big Horn Province. Note, however, that the Devils Tower is significant enough to be the central element of a Landscape Setting.

R O O S E V E L T

NATIONAL

M E M O R I A L P

Squaw Creek
Campground

LITTLE

MISSOURI

RIVER

LANDSCAPE UNIT



A linear land form enclosing a straight reach of quiet water identifies this Landscape Unit (Missouri River, Fergus Co., Mont.)

The Landscape Unit is an area of landscape unified by enclosure. That unified form is essentially spatial—space consisting of a valley, a lake basin, a distinct high plateau bounded by mountain ranges, or a coastal shelf bounded between land and sea. Litton (1968, p. 28–31) uses the term “enclosed landscape,” a similar concept. Examples are an eroded canyon in an otherwise relatively uniform drainage defile, or a special reach of a stream and its trough. Indeed, a river presents a series of connected Units—some more stimulating visually, some less. Yet spatial distinction is the Unit’s most striking visual quality.

The Unit is the landscape element most likely to generate a sense of place. Elements that enclose and surround it tend to make a Unit’s boundaries comparatively clear when its extent is small enough to be observed through limited access or contact. Its enclosed limits and its internal qualities are often recalled in a name—Crater Lake, the Punch Bowl, and Jackson Hole, for example.

The Landscape Unit may be related to the physiographic subsection in scale (Wertz and Arnold 1972, p. 5–6). Tens to hundreds of square miles may be included. Maps of 1:250,000 to 1:1,000,000 scale and larger should prove useful in overall delineation. Topographic maps of 1:62,500 and 1:24,000 will be useful for interpreting characteristics. Scale differences between Landscape Units and Settings are not necessarily obvious.

The term Landscape Unit has been used in widely diverse ways, and unfortunately becomes explicit only within the bounds of specific definition. In our use, the principle of the Unit is its enclosing cohesiveness; additionally it carries the implication of esthetic unity.

In the *Study of the Visual and Cultural Environment* (Res., Plan., and Design Assoc. 1967), the “landscape unit” is identified with surficial patterns laid upon the “landform landscape,” either native or manmade, such as forest on wildlands, or town on farm patterns. This is comparable to Linton’s “land-use landscapes.” Litton’s “visual landscape units,” developed for Lake Tahoe (1971), depend primarily upon spatial characteristics “. . . most generally . . . bowl shape (units with) inward focus toward (lake) water surface. . . .” But six different criteria are used with variable dominance, reflecting marked differences in the visual units. As noted in the discussion of the Landscape Province, the landscape unit in *Water and Landscape* (Litton and others 1974)

was defined as a larger-scale division than the Unit in the present landscape inventory. Additionally, to confound confusion, the landscape unit is a popular and apparently useful term in such studies as Hirvonen’s physiographic-soil-vegetation analysis of Bowen’s Island, British Columbia (1976).

Finally, there is a definite relationship between the Landscape Unit concepts in this report and the “natural corridor” of Lewis used in his study (1963) of the Wisconsin south shore area of Lake Superior.

Scale

The scale of the Unit—its size or area compared with other landscapes—is not wholly dependent upon the observer’s perception of immediate enclosure with positive physical boundaries and the presence of clear internal views. Vividly perceived Units are apt to be relatively open, however, within very strongly enclosed landscapes, which offer few obstructions to sight and exploration. Yet they may be complex.

It is not possible, at any scale, to see all of a landscape or to arrive at useful conclusions about its characteristics and their quality all at once. Gibson (1966, p. 106, 264) shows us that an observer perceives a spatial world which is incomplete and indeterminate; movement is necessary in order to isolate elements from their background and to achieve a sense of form and spatial extent. Winding landscapes require much motion, whereas landscapes in open desert can be seen almost wholly from a single point—not vividly or completely, but usefully. Therefore some motion or access system is a necessary link to the appreciation of scale. Complex landscapes with partially restricted views must be traversed and seen from many angles before their size and limits may be appreciated. Clarence King (1872) conveys this convincingly in his writings—a complex and diversified landscape is worth looking at from many points, in many weathers and seasons.

Though relatively small, the Unit permits considerable exploration. For example, most scenic Landscape Units in which housing is available for visitors also provide a number of scenic trails or roads. In a succession of days, experience can add materially to appreciation of the quality of the total Unit.



A Unit may be relatively large in scale, broad in extent as compared to low enclosure by distant slopes. (Keester Basin near Pathfinder Reservoir, Casper, Wyo.)

The Unit may occur within a Continuity or a Province. Tensleep and Leigh Canyons within the Big Horn Landscape Province constitute a rich and varied Unit with an aggregate length of about 20 miles. The Tongue River Landscape Unit has a length of about 50 miles and includes about 1050 square miles, if watershed lines are taken as approximate limits (*fig. 4*).

Boundaries and Edges

Because the Unit is spatially defined, its topographic boundary or enclosure can readily coincide with local watersheds—and perhaps with administrative boundaries. Considerable variation is to be expected in the elements which ring a particular Unit. Unit boundaries, if distinct and abrupt, can be spectacular. Parts of the enclosure may be cliffs or mountainsides which offer extreme contrasts to the Unit floor; elsewhere the enclosure may consist of gradual slopes, rolling hills, or forest edges or surfaces. In places, the enclosure may be very limited. For example, at the entrance to a broad valley with steep cliff

walls, the floor will not be bounded. Nevertheless, in such an open-ended linear enclosure, the observer will have a strong spatial sense, normally completing the fragmented enclosure (Arnheim 1954, p. 44). The same general tendency permits us to consider some vague areas to be parts of Unit boundaries. In general, the more complete the encircling or enclosing elements and the more positively wall-like they may be, the more vivid the spatial quality.

The bounding enclosure, in all its parts, both vivid and bland, can be a primary source of scenic interest which is further enhanced by a water feature. In addition, slopes permit better display of forest cover where patterns of vegetation type changes, growth, and coloration provide interesting accents. Rock outcroppings and exposed scarps can also add to this visual pattern. Finally, enclosing skylines—the upper horizon—are of special interest because of the dark-light contrast. The sky is nearly always much lighter than even the most brightly illuminated terrain surface; it permits the skyline to be a sharp outline of its typical kind—peaked, rounded, irregular, or smooth.



Top: Bluffs enclose a broad river bend, the bottom enriched by riparian woods and a variety of farmland patterns. (Yellowstone River near Miles City, Mont.)

Bottom: Abrupt, nearby steep slopes are the edges of a small scale Unit; water is invisible but implied by central trees and associated woody plants. (Cracker Box Creek, near O'Fallon Creek and the Yellowstone River, Mont.)



Land Form and Topography

By the requirements for enclosure, vertical or steep topography is normally an important component of the Unit. Wide variations are possible, however, within the general condition that the overall land form be that of an enclosed landscape. As we have seen, the Unit boundaries are primarily land form edges.

The most obvious Units are those presenting the most simple and clear spatial image. This combines flat or concave interior ground surfaces with positive enclosing land form faces—often with a plant cover. These opposing parts may be compared to floors and walls; their proportions—width to height—very much affect the degree of enclosure. Also, as the complexity of the floor topography increases, it tends to interfere more and more with clarity of view. Variable floor topography, along with plants, can se-

verely obstruct the distant enclosing elements and ground details, except from elevated viewpoints. Opportunity for such a viewpoint is offered by a canyon with a rim road, which is followed by descent into the space. The clarity and drama of the canyon form, seen from above, permits considerable complexity and detail to be present within the canyon without creating a sense of spatial confusion.

Within the Northern Great Plains, badlands are typical land forms associated with certain rivers. They form distinctive Landscape Units, a special attraction of the region, as confirmed by such reservations as the Theodore Roosevelt National Memorial Parks on the Little Missouri River, and the Badlands National Monument between the Cheyenne and White Rivers.

Two examples of Units, both including segments of rivers, may be compared (on 1:24,000 scale topographic maps) for their differences of



The sharp river bend, precipitous bluff, and concentric bands of cottonwoods are features that form a distinctive Unit. (Theodore Roosevelt National Memorial Park, North Unit, Little Missouri River N. Dak.)

land form enclosure: a Tongue River Unit within the Tongue River Landscape Province and a Big Horn Unit as defined by the Yellowtail reservoir. On the Tongue River some 6 miles below the reservoir, the river bottom is $\frac{1}{4}$ to $\frac{1}{2}$ mile wide; bluffs close by are 200 to 400 feet high, predominantly much incised, but occasionally eroded into elongated faces. Bottom and bluff vegetation is scant except for pine rimming; meanders make subspaces in the Unit, giving interior view lengths of $\frac{1}{2}$ to 2 miles. Starting just below the reservoir, this Tongue River Unit runs downstream for about 50 miles. The Big Horn Yellowtail Unit is about 18 miles long. Comparatively, it is more visually striking in its proportions than the Tongue River Unit. The impoundment water surface is about half a mile wide with no riparian flat showing; bluffs are 1000 to 1500 feet high within $\frac{1}{4}$ to $\frac{1}{2}$ mile of the water edge; sizeable patches of trees and of scrub are interspersed with barren exposures; meander view lengths are 1 to 2 miles or more.

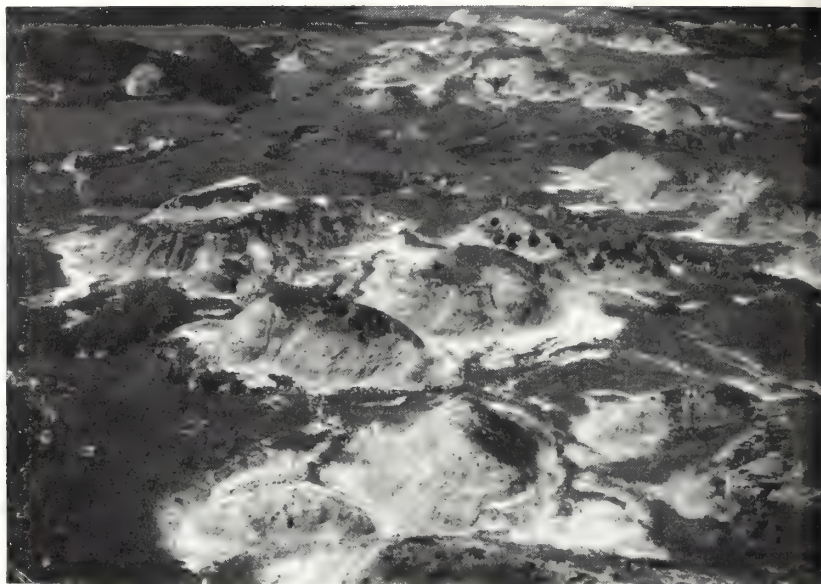
Other examples of Units cited elsewhere help to suggest the great variation to be found at this level of the inventory.

Plant Cover

The scale of the Unit necessarily abbreviates, in amount and variety, the plant cover associated with it. However, the spatial envelope of the Unit brings included plants into close view and contact. Trees may be a significant part of a Unit's visual boundary, whether standing on flat land or on sloping terrain. The usefulness of a single oak in providing shade for a campsite, the quality of aspens framing a lake view, and the display of autumn color in cottonwoods are all the more apparent for their association with the Unit. Because many Units are closely related to streams or water, riparian vegetation frequently provides contrast to nearby mesophytic plants.

Patterns of vegetation may be found in the concentric stands of riparian trees generated periodically by favorable growing conditions. In the Northern Great Plains, with low rainfall, certain Unit orientations produce patterns of tree growth on northerly or protected exposures, with the visual contrasts of barren land, grass, or scrub on opposing exposures. The richness of a Unit is

Top: Badlands are small landscape features, both as individual land forms and as a pattern of bare knobs within a vegetative mosaic. (Strip Creek, near Amidon and Little Missouri River, N. Dak.)



Bottom: A continuous but varied cover of riparian trees and plants forms the central core of a Unit, occupying most of the space within the Unit boundaries. (Near Yellowstone River, east of Miles City, Mont.)



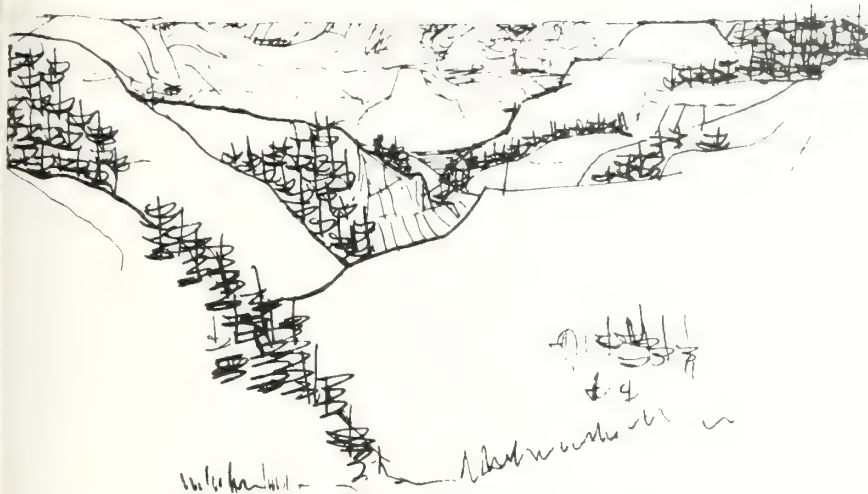
considerably enhanced by different plant types and their seasonal responses.

Water Elements

We have seen that water elements are capable of generating powerful forms and linkages in the larger landscapes, but the innumerable qualities of water are perhaps best appreciated at the scale of the Unit, where they are associated with detail of land forms and plants. The concavity of the Unit is the natural receptacle for water bodies of any size. Conversely, water has been the active agency for the fundamental formation of the

Unit's landscape. A single central stream or water body is dominant within the enclosure of the Unit, although subordinate side tributaries are present. Visual contrasts within the water body—white cascades or quiet dark pools—occur without disrupting the basic unity of the continuous surface (Litton and others 1974, p. 80–81).

Although the emphasis of this study is on the physical, visual elements of the landscape, water seems to trigger a multitude of human responses associated with sound, touch, smell, and memory. The tangible character of water seen at the scale of the Unit has particular potential to contribute positively or negatively to the landscape quality perceived there.



Badlands collectively form a Unit, outer ranks making an enclosure with interior alcoves along complex tributary paths. (Theodore Roosevelt National Memorial Park, North Unit, N. Dak.)

Focal Attractions—Local Features

The quality of a scenic landscape depends upon many different visual impressions. High among these is the sense of unity—characteristic of the Landscape Unit—which is enlivened by focal attractions.

The observer has a tendency to see particular visual elements that are bigger, brighter, or more colorful than the rest, elements that are moving, or that are unique to the local landscape. Water features within the Unit, especially faster water against quiet, reflective water, are examples of such local features. The scale of the Unit may be such that a grove of trees may be a local feature, the more so in many parts of the Northern Great Plains where vegetation tends to be sparse. Individual bluffs, part of a Unit's enclosure, can become notable by reason of greater size, isolation,

or different coloration. It is not likely that such individual elements will be seen or thought of as misfits; their natural form, no matter how novel or striking, prevents that. Badlands topography, as both individual and repeated land forms, also constitutes a special visual feature of the region.

The Unit's form—as a whole or in part—often has the linear configuration of a focal landscape. An example would be a straight reach of stream, its lines leading the eye toward terrain that blocks the view, as in the Unit in the Tongue River Province, described earlier. Visual terminals, such as the bluffs or slopes where a stream bends, are focal areas readily identified. Within a Unit, the character of such focal areas is of special importance; they contribute greatly to visual quality, for better or worse. They are especially prone to degradation through a loss of integrity or unity, because visual impacts here are so obvious.

No 2



Devils Tower

5117

Spring No 1

Belle Fourche

LANDSCAPE SETTING



A conspicuous and dominating feature is the center of complementary surroundings—the Landscape Setting. (Devils Tower National Monument, Wyo.)

G 1:4800 Map Segment: Devils Tower National Monument, Wyoming.

The Landscape Setting is the indefinite area of landscape associated with a scenic feature of particular visual importance. Such a feature has a visual sphere of influence; its value depends greatly on the quality of its setting. Outstanding scenic elements can be easily degraded by surroundings that are detractive or not in proper scale. Large elements require enough space to permit retention of naturalness and to accommodate visitors unobtrusively. Vertical or isolated elements in open country are particularly susceptible to intrusive distractions. On the other hand, smaller lakes in hilly country may require far less protection for their setting, provided that access or distant views are not overly detractive.

Because the Setting is frequently an area designated for management by public agencies—a park, monument, or other protected unit—considerations important to such management are emphasized in this discussion.

The Landscape Setting can be related to combinations of “subsection” or “landtype association” in scale (Wertz and Arnold 1972, p. 5, 6). Tens of square miles may be included. Maps of 1:100,000 to 1:20,000 scale (and larger) are appropriate for delineation and identification.

The scenic features which are frequently the focus of a Setting are commonly described and identified, and often distinctively named. The concept of a visually protective environment

complementary to a feature receives little direct attention in the studies we reviewed.

The “High Site Scenic Areas” or HSSA’s of Dooling (1974) are surface protection areas in which some kind of feature or features are central. Such areas are essentially Landscape Settings. Often they are given park or recreation unit status. Each HSSA is associated with one of the compositional types defined by Litton (1968): feature, panoramic, focal, or enclosed.

Certain elements of Lewis’ (1963) water, topographic, or vegetation resources are inevitably specific features; hence a related Setting may be inferred. Similarly, several of Litton’s landscape compositional types—especially feature, focal, or enclosed types—are related to Settings. The “setting unit” discussed in *Water and Landscape* (Litton and others 1974) is essentially a Setting—a surrounding context for the display of a water feature. In the *Scenery Subgroup Regional Profile*, certain specific key features of the Northern Great Plains are identified. These are dominant elements of Settings. Named examples include the Missouri River Breaks and Signal Butte in Montana; Devil Tower—Missouri Buttes and Cloud Peak in Wyoming; and the Little Missouri Badlands and Sentinel Butte locality in North Dakota. Finally, in the Zube and Dega study (1964), some shoreline types have sufficient visual vividness to be the center point of an established Setting.



A strong vertical element, dominant in the middle distance, is displayed against opposing horizontal ridgelines. (Devils Tower National Monument, Wyo.)



Detail aspects of vegetative pattern—contrasts of life form, edge, texture, and color—may be seen at the scale of the Setting. (Deer Creek, Glendive, Mont.)

Scale

The proper size for a Setting is determined by the scenic element itself, the quality and character of the surrounding landscape, the viewing distance needed, the need to protect drainages, and the need for maintenance or visitor facilities. The need to exclude degrading factors such as moving vehicles, industrial influences, urbanization, automobile or crowd concentrations, or timber harvests which significantly alter the surrounding landscape must also influence the size of the Setting. Topographic factors are likely to be highly significant. In a hilly surrounding, logic may demand the Setting include landscape which is naturally enclosed by those hills. River canyons are examples.

Frequently, topography does not provide adequate natural boundary or site limits. These must then be determined administratively.

A desirable scale for the Setting reflects to some extent the general scale of the surrounding countryside and the travel distances. Scenic elements in open country can become conspicuously restricted if circulation and necessary service crowd the scenic focus. Access corridors are important in the Setting, and should figure in the size of the area. In particular, where travel distances are great, skimpy close-in boundaries are conspicuously out of scale.

Where the surrounding landscape is presently under the control of an agency able to provide adequate protection of the scenic element, the administrative boundaries proposed for the Setting may be more restrictive without loss of control. Special consideration should then be given to

approach roads, because these serve to set the scale for observers. Boundary indicators in the shadow of the main feature are likely to create a restrictive sense of administrative enclosure. Entrance signs, gates, or kiosks all set the stage; their position is important in affecting scale.

The relation of the Setting to the scenic element may be illustrated by Devils Tower National Monument, which in itself includes an area of about 2 square miles. Estimated size of a Devils Tower Setting would be 15 to 20 square miles—a star-shaped area reflecting access corridors.

Boundaries and Edges

The administrative boundary of the Setting, if coincident with topographic features, may be visible and thus noticeable; preferably, however, it should seem to flow into the surrounding landscape. The Setting is best considered a part of a larger landscape in which the scenic feature is experienced locally as dominant. But it is supported by the normal, subordinate natural elements in the area. The actual site may then exist principally as an administrative domain.

The Devils Tower Setting illustrates a study method for arriving at the Setting boundary. It is evident that there is a sphere of influence radiating from this conspicuous volcanic neck. All of the places from which this feature is visible may be plotted, using computer-assisted methods (Amidon and Elsner 1968), especially from access corridors, and these places are then given planning consideration, either for actual site reservation or administrative control. Similarly, at the Tower itself, a plan plot may be made of the directly visible



Setting features are seen here in a skyline silhouette; the Setting boundary is clear because of contrasts between land form and accompanying plant cover. (Missouri Buttes and Devils Tower, Wyo.)

surrounding landscape. These are mechanical steps, subject to interpretation and later consolidation, but they help to determine realistic boundaries, based on actual conditions.

Other kinds of Setting features, especially water elements, may not lend themselves directly to visual plotting, but they also have a definable sphere of influence. Topographic eminences related to water features could be used in plotting visible surfaces; related drainages would then strongly affect the Setting limits. Stream corridors may serve concurrently as access corridors.

Land Form and Topography

In the Setting the principal scenic feature occupies center stage. The feature is often a distinctive land form—such as the Devils Tower, but its topographical surroundings—the Setting—determine the overall level of quality seen. The hill forms and mesa-like ridges about Devils

Tower present a strong horizontal contrast to the vertical neck. In a lake feature, the lake basin determines overall scenic value as much as the water surface itself, and is often of even greater importance.

Topography can serve to screen roads, trails, service buildings, or other visitor facilities from direct view, when their visible presence may detract from the scenic quality. Even modest alterations to ground surface may be effectively used for this purpose. The topographical alterations that are necessary for the siting of buildings or roads should be carefully blended with natural surfaces to avoid conspicuous variations from typical surrounding slopes.

Nearby topography can often be employed to gain variety in possible views of the scenic element. Panoramic views may be possible from elevated positions, or variety in approach road elevations may be achieved. Within the Setting, trails can also provide the best viewing if their location takes maximum advantage of topographic change.



Top: A Setting feature, Pompeys Pillar, is here combined with a Landscape Unit. (Pompeys Pillar, Yellowstone River, Mont.)

Bottom: Detailed aspects of water and shore edge plant associations are small-scale impressions characteristic of both Settings and Units. (Near Underwood, N. Dak.)

Focal Attractions and Local Features

The scenic feature itself is visually dominant in the Setting, and the focus of most visitors' attention. Intelligent planning can provide enhancement, however, through approach roads and trails which give a full range of views for appreciation of the Setting's scenic quality. Visitor facilities need to be visually subordinate and should not occupy focal positions.

Local features may be small and relatively detailed within the Setting—especially related to the scale of pedestrian attention. Within the Devils Tower Setting, they include typical plant associ-

ations such as a cottonwood grove, small lava extrusions, a creek, and a segment of the Belle Fourche River.

Water Features and Elements

Water within the Setting may be either the central and main feature, or a part of the general landscape within the Setting. In the Devils Tower Setting, a mile or so of the Belle Fourche River is included, as are minor creeks. They have had a function in the creation of this landscape, and they provide secondary interest to the main feature.

The discussion of water in the section on Landscape Units is generally applicable to the Setting as well.

Plant cover contrasts—grass against woody plants, hardwoods against conifers — are apparent and appreciated close at hand. (Black Hills, S. Dak.)



Plant Cover

Plant cover, in the form of unusual or even unique plant associations, can be the central feature of a Setting. Examples are a relic plant island, a small forest ecologically related to a particular soil formation, or an old-growth grove. Usually established for scientific purposes, these special aggregations of plants do provide a subtle kind of local scenic landscape. The Setting adds to this central element a buffer area, both visual and actual—in part consisting of plant cover typical of the locale.

In establishment of the Setting, local protection of scenic values should be the primary consideration. Normally, the presence of a special scenic land form feature would not create an interruption in the characteristic plant cover. Plant cover within the Setting may be considered similar in scale and detail to that within the Landscape Unit. Normal objectives for planning would be to maintain typical local cover, avoid intrusions of

inappropriate exotic plantings, and seek cooperative design control of such major landscape manipulations as nearby timber harvesting.

The integrity of the Setting's landscape and its plant cover may be easy enough to maintain, but there should also be no abrupt changes in management practices at the boundaries and visual surroundings of Settings. If a protected but highly visible Setting is established within a visibly fragmented surrounding landscape, there is general loss of scenic value. Isolation and protection of the best parts is not the answer. In general, management practices must be especially attuned to the varied scenic values of the Setting, including its plant cover.

Planting to provide shelter or screening should augment the native landscape character wherever possible. When this course is impractical, plants that meet the visual requirements for similarity are often available. Obvious contrasts should be avoided: regional characteristics of plant types in size and color should be respected, and close plant family associations sought wherever possible.

APPENDIX

A. Maps and High-Altitude Imagery

The usefulness of high-altitude imagery and topographic maps of the Northern Great Plains in making landscape inventories was evaluated. In particular, information was sought which might delineate the boundaries between different inventory elements, and help identify characteristics of landforms, vegetation, and land use patterns. Samples of high-altitude imagery were limited to standard photographic prints on paper. Interpretation was limited to direct examination with and without magnification and with simple stereoscopes. Although these methods do not take full advantage of the medium, we assumed that more sophisticated interpretation, using other photographic products and advanced equipment, would be unrealistic, because it would not ordinarily be available to land managers.

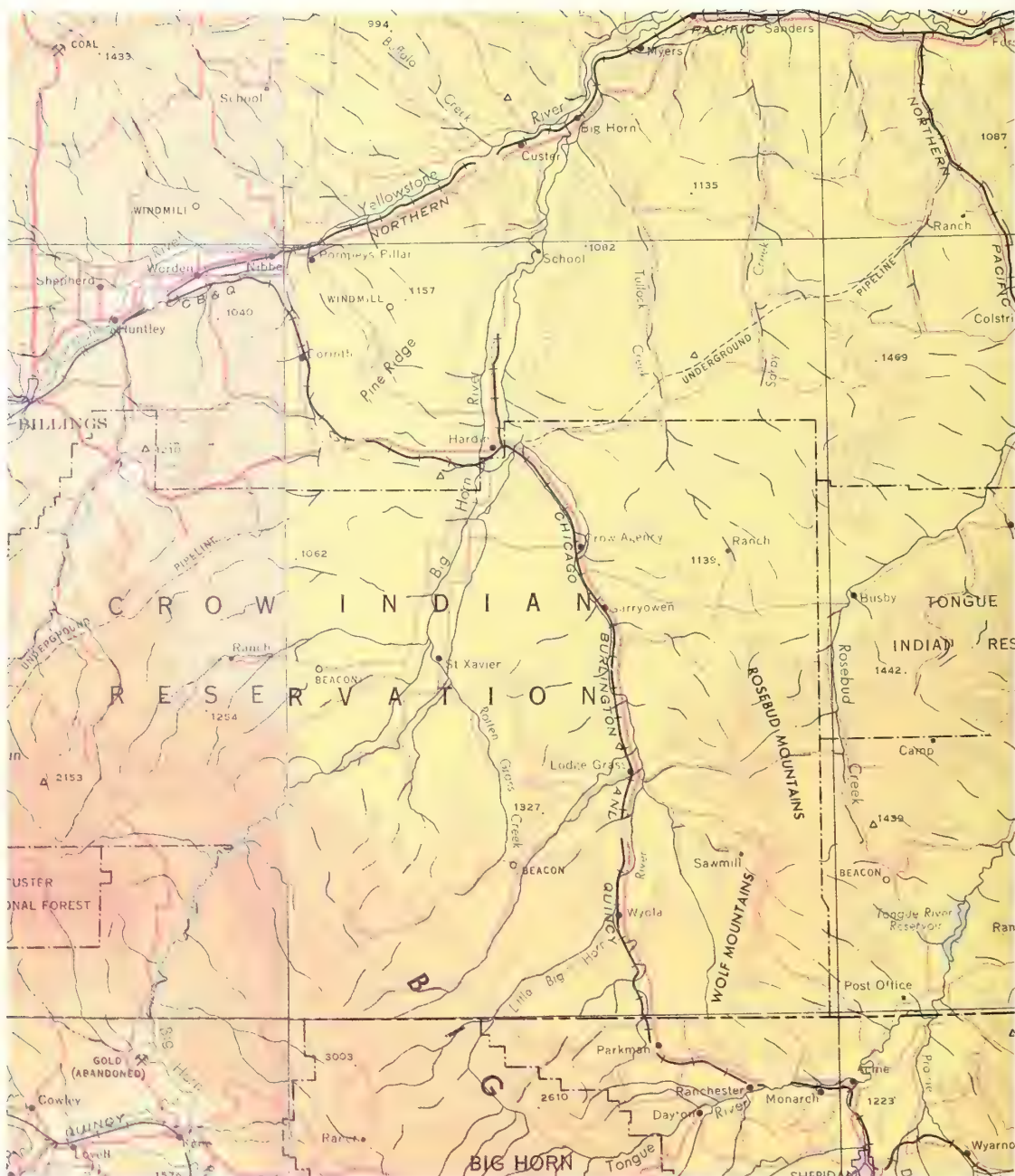
Our use of remote sensing material is limited to some samples of imagery from ERTS (Earth Resources Technology Satellite), and Skylab, or EREP (Earth Resources Experimental Package). These represent only an introduction to the possibilities, but further investigation was beyond the scope of the project. The material from ERTS and Skylab was obtained from the EROS (Earth Resource Observation System) Data Center, Sioux Falls, South Dakota.

The procedure for obtaining high altitude imagery from the EROS Data Center is simple but may take several months to complete. An inquiry form for geographic search (available from the Center) is helpful. For each point of interest, the form calls for geographic coordinates; for each area of interest, area corner coordinates are required. The Center makes a computer search and provides a printout sheet showing the coverage, types, and quality of imagery available. (About three weeks or more should be allowed for receipt of this printout.) From the printout, the choice of available imagery and photographic product can be

made. (About six weeks should be allowed for delivery of the material ordered.) Note: Prices shown (1978) are subject to change.

With each image of a different scale, a corresponding topographic map is provided. The map is a material aid to interpretation, especially of black and white prints at smaller scales (1:1,000,000 to 1:250,000). Topographic maps at a variety of scales have potential use in landscape inventories that has not been exploited. The matched sets of sample segments of topographic maps and high-altitude imagery allow comparison of clarity in resolution and detail. Scales of coverage range from 1:1,000,000 to 1:31,400. Information on the original and complete maps, which are available from the U.S. Geological Survey (USGS) and the National Oceanographic and Aeronautical Administration (NOAA), is given for each sample. The following maps and photos are included:

1. Billings and Yellowstone River, Montana
Topographic Map (USGS, 1:1,000,000)
ERTS Black and White Composite
2. Colstrip, Lamar, Montana
Sectional Aeronautical Chart (NOAA, 1:500,000)
Skylab Color Photo
3. Billings and Yellowstone River, Montana
Sectional Aeronautical Chart (NOAA, 1:500,000)
Skylab Infrared Color Photo
4. Theodore Roosevelt National Memorial Park, North Dakota
Topographic Maps (USGS, 1:250,000)
ERTS Black and White Composite
ERTS False Color Composite
Skylab Color Photo
5. Theodore Roosevelt National Memorial Park, North Dakota
NASA Aircraft Infrared Color Photo
USGS Air Black and White Stereo Photo



Billings and Yellowstone River, Montana

Map

USGS World (North America) Series, 1:1,000,000
 Parts of two sheets: Bighorn Mountains NL13 and Yellowstone
 NL12. 1955. \$1.00 per sheet
 Limits: long. 102° to 108° W (NL13) and 108° to 114° W (NL12);
 lat. 44° to 48° N
 Contour intervals: 150, 300, 500 meters, with tints
 Scale: 1 in. = 15.78 (16) miles, 1 cm = 10 km; 1 in² = 249.1
 miles², 1 cm² = 100 km²

Image

ERTS black and white composite, bands 5 and 7.
 Center coordinates: (Cooke City, Mont.) N 45°00' X
 W 109°55'
 Special order.
 Limits: long. 104° to 115¼° W, lat. 40½° to 49° N
 Scale: 1:1,000,000 (1:1,065,600; 1 in. = 16.6 miles)



Application

Landscape Continuity, Province

Landforms and Topography: Gross differences (and edges) apparent between Northern Great Plains Continuity and the Bighorn Mountains Landscape Province; not apparent for the Tongue River Ponderosa Pine Upland Province.

Plant Cover: Different vegetation types and their patterns not visible.

Water—River Drainages: Larger streams and reservoirs clear; density of streams and drainage patterns range from apparent to clear.

Land-use Patterns: Agricultural crop patterns faintly visible; urbanization, roads, and disturbances not visible.



Colstrip, Lame Deer, Montana

Map

NOAA sectional aeronautical chart, 1:500,000
 Billings. October 1973-April 1974. \$2.00
 Limits: lat. 44½° to 49° N, long. 101° to 109° W
 Center coordinates for Lame Deer: N 45°37' x W 106°40'
 Contour interval: 500 ft
 Scale: 1 in. = 7.89 (8) miles, 1 cm = 5 km; 1 in.² = 62.25 miles²,
 1 cm² = 25 km²

Image

Skylab color, S190B
 Center coordinates: N 45°41'48" X W 106°56'15"
 4.5 in. G 20B08115000000, June 9, 1973, 8.6- X
 8.6-in. enlargement. \$12.00
 Quality 8, cloud cover 0%
 Scale: Same as map.



Application

Landscape Continuity, Province

Landforms and Topography: Consistency of small elements apparent, all within the Tongue River Ponderosa Pine Uplands Landscape Province.

Plant Cover: Darkness of conifer cover clear to apparent; contrast between conifer cover and scrub and grass apparent; difference between grass and scrub not apparent.

Water-Stream Drainages: Streams and dense drainage patterns clear.

Land-use Patterns: Agricultural crop patterns clear; roads clear to faint; urbanization apparent as disturbance (Lame Deer, Crow Agency); disturbance clear (Colstrip mining).

General: Much more informative than ERTS image.



Billings and Yellowstone River, Montana

Map

NOAA sectional aeronautical chart, 1:500,000
 Billings. October 1973—April 1974. \$2.00
 Limits: lat. $44\frac{1}{2}^{\circ}$ to 49° N, long. 101° to 109° W. Center coordinates for Billings: N $45^{\circ}45'$ x W $108^{\circ}32'$
 Contour interval: 500 ft
 Scale: 1 in. = 7.89 (8) miles, 1 cm = 5 km; $1 \text{ in.}^2 = 62.25 \text{ miles}^2$, $1 \text{ cm}^2 = 25 \text{ km}^2$

Image

Skylab color infrared photo, S190A CIR. 2.2 in. 20A00911300000,
 Center coordinates: N $45^{\circ}58'27''$ X W $107^{\circ}54'35''$
 June 9, 1973,
 Quality 8, cloud cover 10%
 12.8- X 12.8-in. enlargement. \$15.00
 Scale: Same as map



Application

Landscape Continuity, Province

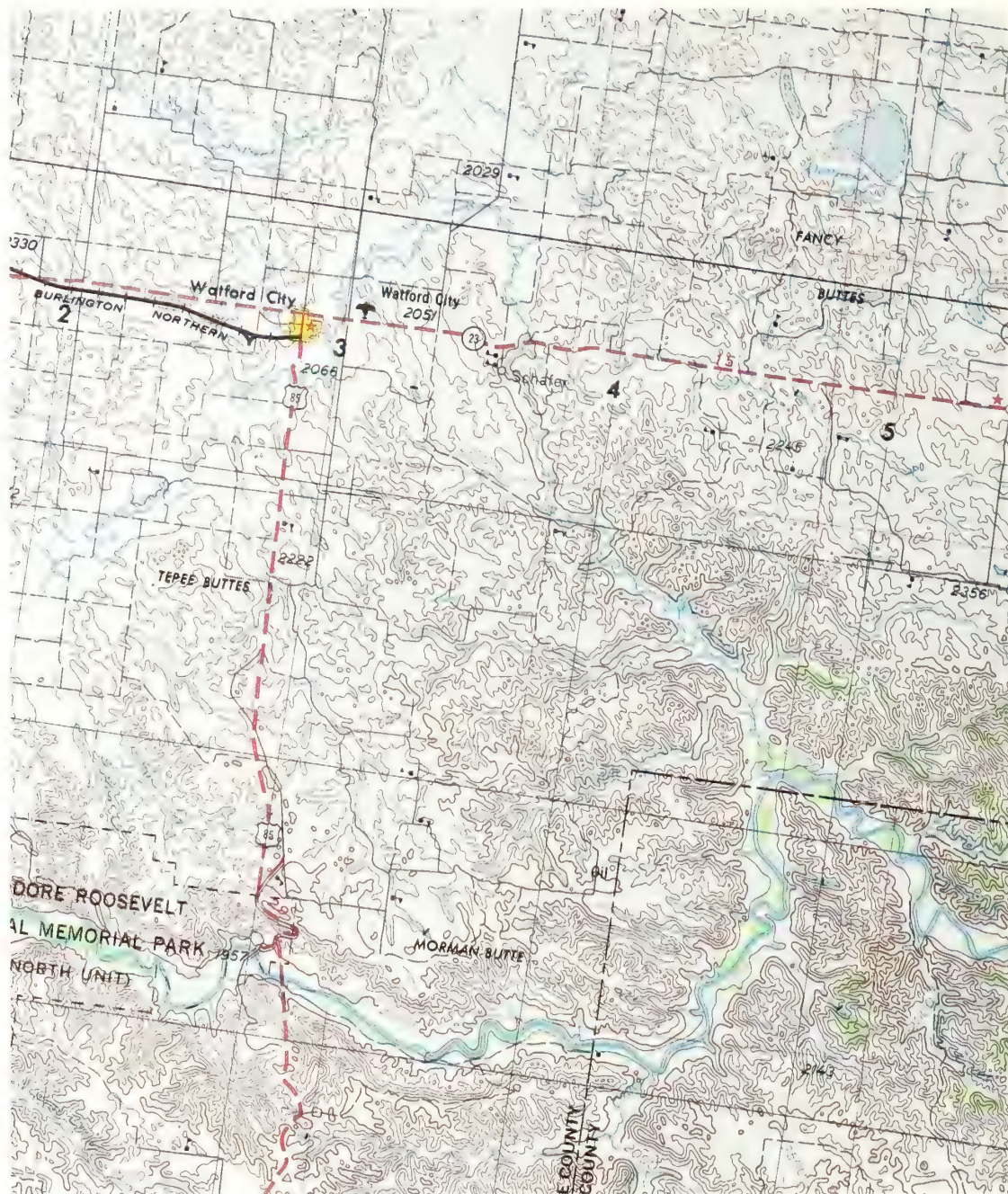
Landforms and Topography: Textural character and scale typical of the Landscape Continuity apparent, separable from texture and scale of adjacent Tongue River Ponderosa Pine Uplands Province.

Plant Cover: Conifer cover apparent to faint as darker tonal areas; contrast between conifer cover and scrub/grass faint; riparian cover clear but connective with blocks of lush growth crops.

Water-Stream Drainages: Streams and creek drainage patterns apparent to clear.

Land-use Patterns: Agricultural crop patterns clear, especially lush-growth fields; roads and railroads apparent to faint; urbanization faint, indefinite tonal texture (Billings).

General: Useful in combination with Skylab color at the same scale.



Theodore Roosevelt National Memorial Park, North Unit, Little Missouri River and Watford City, North Dakota

Map

USGS Army Map Service, U.S. Series, 1:250,000 Watford City,
North Dakota NL13-3, 1953, limited revision 1967. \$1.00
Limits: lat. 47° to 48° N, long. 102° to 104° W
Center coordinates for Theodore Roosevelt National Memorial
Park, North Unit: N 47°37' X W 103°22'
Contour interval: 100 ft (50 ft to 200 ft in series)
Scale: 1 in. = 3.95 (or 4) miles; 1 cm = 2.5 km; 1 in.² = 15.57
miles², 1 cm = 6.25 km

Image

ERTS black and white
Center coordinates: N 47°24'59" X W 103°54'59" 2.2
in., 81157170445G000, November 27, 1974, 29.2-
X 29.2-in. enlargement. \$20.00
Quality 8, cloud cover 10%
Scale: Same as map



Application

Landscape Continuity, possibly Province

Landforms and Topography: Fine texture of badlands apparent, separable from adjacent smoother terrain.

Plant Cover: No reliable indication of vegetation type differences; darker tones associated with badlands forms possibly related to vegetation.

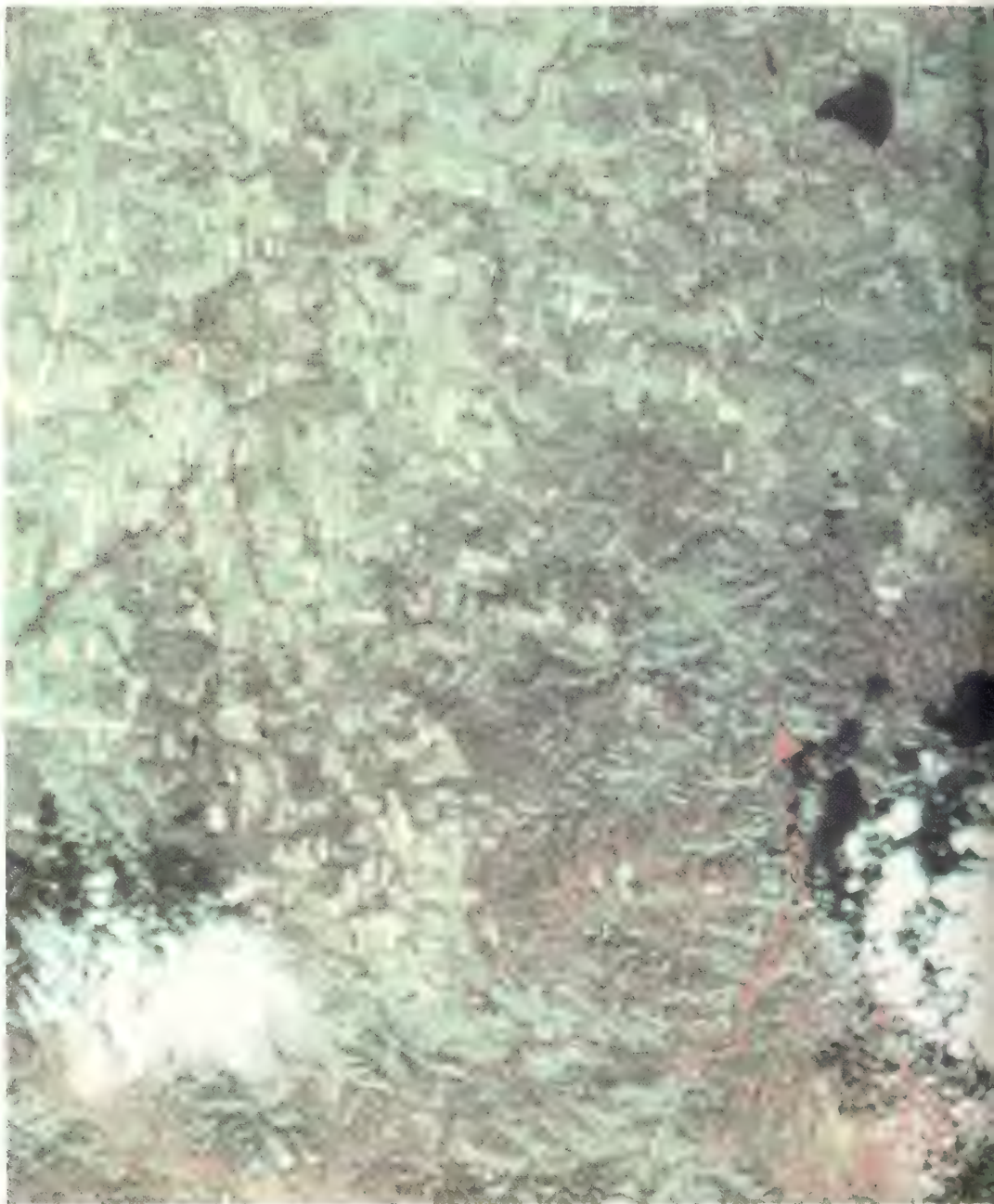
Water-Stream Drainages: River surface apparent (Little Missouri); lesser stream patterns faint.

Land-use Patterns: Agricultural crop patterns faint; roads and urbanization (Watford City) not visible.

General: Not significantly different from ERTS at 1:1,000,000 scale.

Image

ERTS false color
composite
Center coordinates: N
47°26'06" X W
102°34'34"
81388171115N200.
August 15, 1973, 29.2- X
29.2-in. enlargement.
\$50.00
Quality 8, cloud cover
10%
Scale: Same as
map—1:250,000.



Theodore Roosevelt National Memorial Park, North Unit, Little Missouri River, North Dakota

Application

Landscape Continuity and (marginally) Province

Landforms and Topography: Fine texture of badlands apparent, separable from adjacent smoother terrain.

Plant Cover: Riparian cover and pattern clear; vegetation associated with badlands apparent; vegetation type separations suggested but indefinite.

Water-Stream Drainages: River and lake surfaces apparent (Little Missouri, Demicks Lake); stream patterns apparent as associated with riparian cover.

Land-use Patterns: Agricultural crop patterns apparent to clear; roads not visible; urbanization suggested but indefinite (Watford City).

General: Significantly more informative than ERTS black and white.



Image

Skylab color, S190B
 Center coordinates: N
 47°58'05" X W
 102°53'01" 4.5 in.,
 G30B08623400000
 September 11, 1973,
 17.1- X 17.1-in.
 enlargement. \$25.00
 Quality 8, cloud cover
 10%
 Scale: Same as map—
 1:250,000

Theodore Roosevelt National Memorial Park, North Unit, Little Missouri River, North Dakota

Application

Landscape Province and Unit

Landforms and Topography: Fine texture of badlands clear, readily separable from less dissected forms of adjacent smoother terrain.

Plant Cover: Riparian vegetation apparent; darker tonal patterns associated with badlands apparently related to vegetation, medium tones apparent as grass/scrub cover and contrasting to darker (woody) vegetation within drainage defiles.

Water-Stream Patterns: River and lake surfaces clear (Little Missouri, Demicks Lake); meander creek patterns clear and separable from upland drainage patterns.

Land-use Patterns: Agricultural crop patterns very clear; road faint to clear, urbanization clear (Watford City); disturbance detectable to clear.

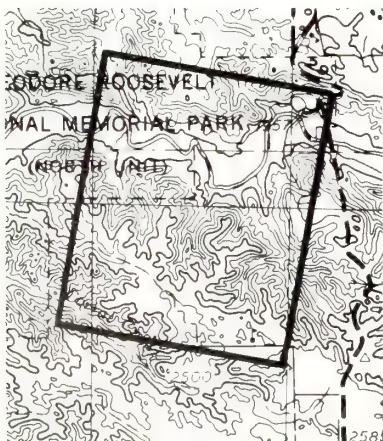
General: Infinitely superior to all other images at 1:250,000 scale.

Image

NASA aircraft color infrared (stereo available)

Center coordinates: N 47°35'29" X W 103°19'17" 6317001400023, frame 27, August 30, 1975. 9- X 9-in. print, \$7.00 (EROS Data Center)

Quality 8, cloud cover 0%
Scale: 1:52,000; 1 in. = 0.82 (4/5) mile, 1 cm = 0.51 km; 1 in.² = 0.67 mile² (429 acres), 1 cm² = 0.26 km²
Index maps: Enlargements from 1:250,000 map (see page 72).



Theodore Roosevelt National Memorial Park, North Unit, Little Missouri North Dakota

Application

Landscape Unit and Setting, Boundaries of Continuity and Province

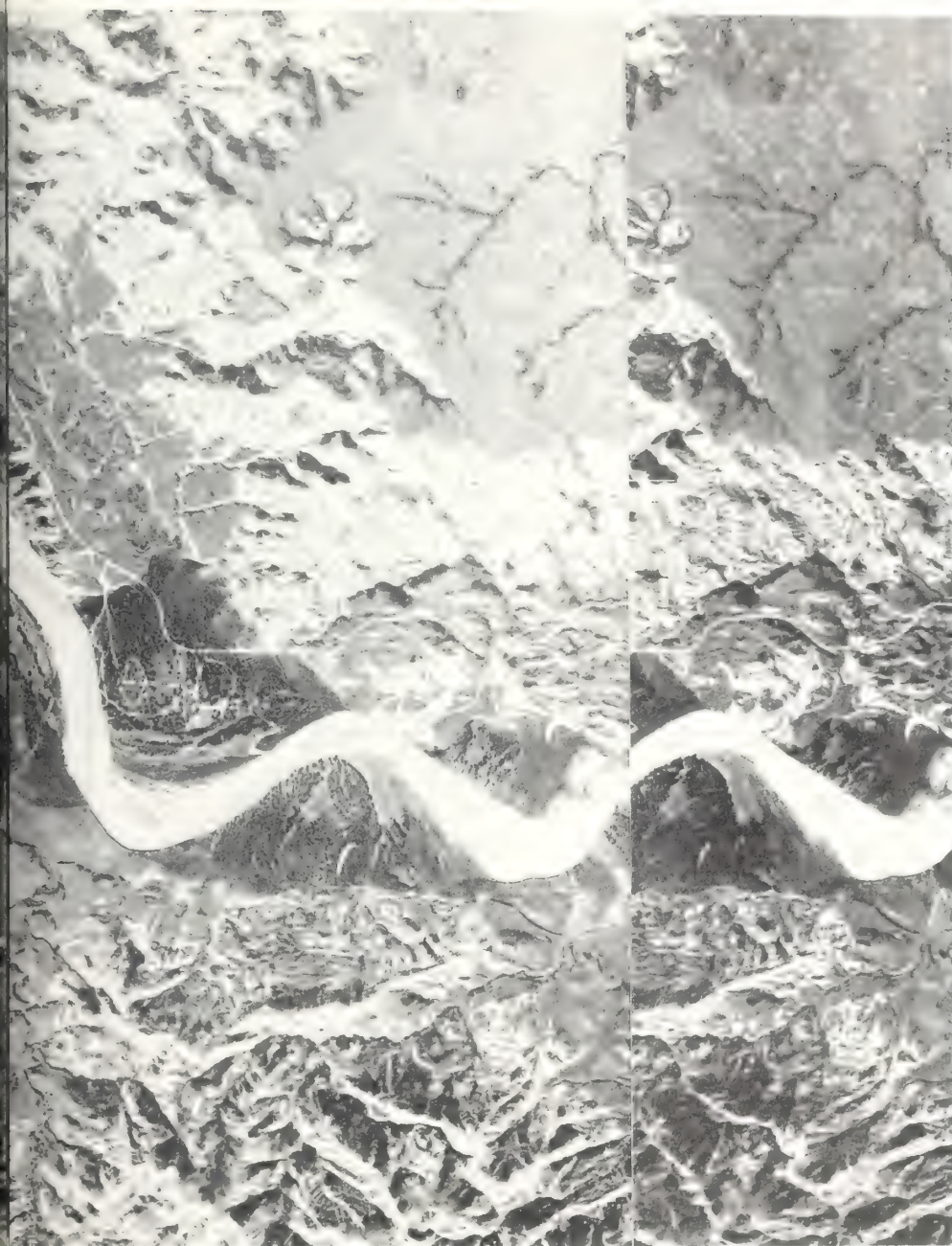
Landforms and Topography: Pattern and form of badlands clear and detailed, readily separated from less dissected forms of adjacent smoother terrain.

Plant Cover: Riparian woodlands and stringers very clear; (woody) vegetation in upper drainage defiles very clear; grassland and scrub contrasts faint to apparent; barren (erosion) areas apparent to clear.

Water-Stream Patterns: River stream patterns and pond surfaces clear; meander creeks clear and readily separable from upland drainage patterns; associations with riparian vegetation clear and detailed.

Land-use Patterns: Agricultural crop patterns very clear—some with wetlands or lush growth very clear to apparent; urbanization (buildings and associated patterns) clear; disturbances (clear cuts, fills, cleared areas) clear.

General: Superior in contrast to comparable NASA color, but the combination is useful. Superior in resolution and detail.



Image

USGS air stereo, black and white (stereo pair)

Center coordinates: N 47°37' X W 103°22' 1F 44 GS CDO and 1F 45 GS CDO August 20, 1956. (set of 5) \$10.00 (USGS National Cartographic Information Center, Reston, Va.)

Scale: 1:31,428, 1 in = 2619 ft, 0.50 mile; 1 cm = 0.31 km; 1 in.² = 0.25 miles², 1 cm² = 0.096 km²

Theodore Roosevelt National Memorial Park, North Unit, Little Missouri
r, North Dakota

Application

Landscape Unit and Setting

Forms and Topography: Landform patterns, form, and slope differences very clear in detail; ion of types clear.

Cover: Riparian woodlands and patterns very clear; (woody) vegetation in drainage defiles and herly surfaces clear; grassland and scrub contrasts faint to apparent; barren (erosion) surfaces clear.

Stream Patterns: River stream patterns and surfaces clear; meander creek patterns clear and separable from upland drainage patterns; riparian vegetation associations clear and detailed.

Use Patterns: Agricultural crop patterns and urbanization not present but very clear in adjacent of the sortie; roads very clear; disturbances very clear.

al: Superior resolution in detail although less informative than color; highly useful in determina- boundaries between the various visual inventory elements.



B. Visual Landscape Terminology

The following abstracts present terms and concepts that have been used in visual landscape analyses, inventories, and assessment procedures.

Each abstract has three parts: (1) Terminology, (2) Scale of application, and (3) Objectives. Only studies based upon the visual or scenic landscape resource are included. Studies are broadly grouped, and range from general to specific.

Terminology is presented without definition and without comment. Repeated occurrence of similar terms suggests that they are accepted to a certain degree, but meanings may well have shaded differences. Obviously there is no standardization at this time and no authority that might effect standardization can be identified.

Scale of application attempts to suggest the general scale of the study being reviewed and the map scales used. Publication graphics affect what may be shown, and can fundamentally alter the most desirable working scales. It is therefore important to be aware that proportional scales, when cited, are taken from the published maps or from the text.

Objectives briefly summarize the major goals of each study chosen for review.

Regional or Large-Scale Studies

Linton, David L.

1968. The assessment of scenery as a natural resource.

Terminology

Landform landscapes

Relative relief

Lowland

Hill Country

Bold hills

Mountains

Plateau uplands

Low uplands

Significant water elements

Land-use landscapes

Urbanized and industrialized landscapes

Continuous forests

Treeless farmland

Moorland

Varied forest and moorland landscapes

Richly varied farming landscapes

Wild landscapes

Scale of application

All of Scotland, 30,400 square miles, (78,730 km²), 145 miles (235 km) wide by 275 miles (445 km) long. Studies at 1:634,000 (1 inch = 10 miles, 1 cm = 6.3 km), published at 1:3,168,000 (1 inch = 50 miles, 1 cm = 31.68 km).

Objectives

Identify, compare, and discuss scenic resources, and finally summarize them with an (arbitrary) numerical rating system.

Research, Planning and Design Associates

1967. Study of the visual and cultural environment; North Atlantic regional water resources study.

Terminology

Landscape series—natural element

Mountain subseries

Steep hill subseries

Rolling hill subseries

Undulating land subseries

Flat subseries

Coast line subseries

Compound subseries

Landscape unit—manmade element—pattern

Center City

Intermediate city

Fringe city

Town/farm

Farm

Farm/forest

Forest/farm

Forest/wildland

Scale of application

Northeastern tier of states, North Carolina to Canada, 167,000 square miles (435,000 km²).

Objectives

Define broad area landscape inventory and assessment procedure; ranking or weighing values are based upon (arbitrary) numbers. Visual landscape is represented also by typical topographic sample and excellent sketches.

Surface Resources Work Group, Northern Great Plains Resources Program

1973. Scenery subgroup regional profile.

Terminology

Level plains

Hilly country

Flat open country

Rolling open country

River breaks
Scattered Ponderosa Pine country
Gently rolling prairies with low hills
Badlands
Lake and pothole country
Buttes
Vast rolling grasslands
Mountains

Scale of application

Northern Great Plains, basis of the study:
Hammond's *Physical Subdivisions* map in
National Atlas of the U.S.; work plotted
on 1:1,000,000 (1 inch = 16 miles, 1 cm = 10
km) map.

Objectives

Identify visual landscape resources of North-
ern Great Plains, based upon judgment of
experienced landscape architects familiar
with the area. Criteria not explicit but in-
cluding "character of topography, vegeta-
tive variety, unique landform features, land
use patterns and a brief description of the
scenic qualities of the (landscape) subdivi-
sion or category."

County-Scale and National Forest Studies

Lewis, Philip H., Jr.

1963. Landscape analysis 1—Lake Superior
south shore area.

Terminology

Natural corridors
Manmade corridors
Environmental corridors
Corridor fringe
Surface, slope rim
Water resources (list)
Wetland resources (list)
Topographic resources (list)
Vegetation resources (list)
Historical and cultural resources
Archeological resources (list)
Wildlife resources (list)
Tourist service facilities

Scale of application

County mapping, 1:125,000 (1 inch = 2 miles,
1 cm = 1.25 km).

Objective

Map county-scale areas, incorporating as-
sessment of landscape resources, intrinsic
and extrinsic values, through an (arbitrary)
point system.

U.S. Forest Service

1974a. National Forest landscape management,
vol. 1.

Terminology

Basic concepts

Characteristic landscape (includes Litton's
types)

Variety

Deviations

Dominance elements

Form, color

Line, texture

Dominance principles

Contrast, convergence

Sequence, codominance

Axis, enframement

Variable factors

Motion, scale

Light, time

Atmospheric conditions, season

Distance, observer position

Landscape character analysis

Landscape management alternatives

Deterioration, destruction

Preservation, enhancement

Retention, modification

Rehabilitation

Scale of application

National Forest lands context, land use plan-
ning and landscape management scales.

Objectives

Present national forest servicewide approach
to landscape management development;
establish terminology and illustrate con-
cepts. Includes a limited glossary of land-
scape management terms.

U.S. Forest Service

1974b. National Forest landscape management:
the visual management system, vol. 2 chap. 1.

Terminology (as in vol. 1, with additions)

Character type and subtype

Variety classes

Distinctive

Common

Minimal

Sensitivity levels

Highest

Average

Lowest

Quality objectives

Preservation

Retention, partial retention

Modification, maximum modification

Unacceptable modification

Scale of application

National Forest land use and landscape management planning use, mapping shown at 1:42,240 (1 inch = 0.67 miles, 1 cm = 0.42 km) and 1:56,316 (1 inch = 0.89 miles, 1 cm = 0.56 km) probable application at 1:62,500 to 1:125,000.

Objective

Define and map physical landscape quality according to variety classes and distance zones, delineate landscape quality in relation to user's concern for landscape (sensitivity level), so as to identify a visual quality objective for management decision.

Route and Travel Corridor Studies

Burke, Hubert D., Glen H. Lewis and Howard R. Orr

1968. A method for classifying scenery from a roadway.

Terminology

Characteristic landscape
Roadside zone
Outer zone
Far zone

Scale of application

Road or stream corridors, inventories based on visible landscape.

Objective

Define a road-based landscape evaluation procedure with the characteristic landscape as normal or modified by either a positive or negative rating.

Dooling, J. Peter

1974. The golden circle: toward a park and outdoor recreation plan.

Terminology

Landscape image analysis
Landscape continuum, scenic nodes
Imageability, imageable (highly, less, least)
Image (strong, weaker)
Visual use, physical use
Spatial definition, visual order
Visual complexity
Kinesthesia
Ecological dynamics
Edge (degree, types)
Compositional types (Litton)
Form, light, color, texture
Observer position and distance

Landscape transparency

High site scenic areas (HSSA's)

Scale of application

Visual travel corridor of the Golden Circle highways, northern British Columbia, approximately 1200 miles long. One HSSA identified in each (arbitrary) 70-mile segment. Field maps: 1:50,000 (1 inch = 0.79 miles, 1 cm = 0.5 km) reproduced at 1:64,100 (1 inch = 1.1 miles, 1 cm = 0.64 km).

Objective

Protect basic values of the area, develop park-recreation systems appropriate to the region, develop a mapping framework and visual display of HSSA's to serve as coordinative for all resources, consider trade-offs and alternatives, prepare long range plans for landscape and historic preservation and outdoor recreation, provide a benchmark study.

Litton, R. Burton, Jr.

1968. Forest landscape description and inventories—a basis for land planning and design.

Terminology

Factors of scenic analysis and observation
Distance (foreground, middleground, background)
Observer position (inferior, normal, superior)
Form (isolation, size, silhouette, surface variation)
Spatial definition (proportions)
Light
Sequence
Compositional types
Panoramic landscape
Feature landscape
Enclosed landscape
Focal landscape
Canopied landscape
Detail landscape
Ephemeral landscape

Scale of application

Route inventories, road and stream corridors, 1:62,500 (1 inch = mile, 1 cm = 0.625 km) working studies at scale of 1:24,000 and 1:62,500.

Objective

Identify and define visual landscape resources; apply scenic analysis and field recording to various inventory methods, case studies.

Water Emphasis Studies

itton, R. Burton, Jr.

1971. Visual landscape units of the Lake Tahoe region.

Terminology

Spatial characteristics

Enclosures, cohesive skyline

Headland and shoreline spurs

Floor or flattened lower and central slopes

Cove indentations, water edge

Conspicuous, dominant landforms, scarps or lakes

Visually distinct forest stands, and other plant associations

Visual subdivisions: landscape units and subunits

Scale of application

Lake Tahoe watershed, 500 square miles, (1290 km²) (including 190 square miles (495 km²) of water surface).

Field work on 1:62,500 (1 inch = 1 mile, 1 cm = 0.625 km) map, reproduced at 1:125,000 (1 inch = 2 miles, 1 cm = 1.25 km).

Objective

Identify and describe visual landscape units and their scenic content, indicate visual impacts present or potential, "—suggest developmental constraints that may respond to visual clues found in the landscape."

itton, R. Burton, Jr., Robert J. Tetlow, Jens J. Jørgensen, and Russell A. Beatty.

1974. Water and landscape—an aesthetic overview of the role of water in the landscape.

Terminology

Unity and visual units

Landscape unit

Boundary definition

General form—terrain pattern

Features

Vegetation patterns

Water presence

Characteristic weather

Cultural and land use patterns

Setting unit

Landscape expression

(subheads similar to those under

Landscape unit)

Water expression

Prominence

Continuity

Transition

Evidence of human impact

Waterscape unit

Water element

Spatial expression and edge

Movement and features

Appearance

Aquatic environment

Evidence of human impact

Shore element

Edge definition, vertical and longshore

Spatial expression

Edge features

Riparian environment

Evidence of human impact

Manmade structures or alterations in units

Linear elements

Area elements

Mass elements

Point elements

Color and texture

Scale of application

Hierarchical in scale: (1) landscape unit is regional, including a series of visually similar rivers or streams, (2) setting unit is a stream segment and its terrain enclosures, (3) waterscape unit is detailed inventory of a stream segment.

Objective

Discuss esthetic character of water, develop a landscape inventory method emphasizing water presence, appraising manmade changes relative to water. Includes high-low landscape quality ranking lists using unity, variety, and vividness as esthetic criteria.

Zube, Ervin H. and Hugh A. Dega

1964. Wisconsin's Lake Superior shoreline—3

Terminology

Visible physical features

Shoretupes, A to N, 13 types

Wet beach, dry beach, bluff, upland, etc.

Scale of Application

County mapping—shoreline 1:500,000 (1 inch = 8 miles, 1 cm = 5 km). Shore type profiles (1 inch = 50 feet, 1 cm = 15.2m).

Objective

Specify characteristics, summarize climate, vegetation, topography, services, etc.; analyse visual landscape, shore, beach, clay bluffs, sandstone bluffs and caves, sloughs, etc.; compare quantitatively shore types, primarily by linear measurement, and determine their attributes.

C. Criteria for Recording Ground Reconnaissance

Our landscape field recording with photographs and sketches was carried out according to the following criteria:

1. Document the usual as well as the striking—the ordinary landscape, which has relative homogeneity because of repetitive land form, vegetation, and water elements, as well as the unusual landscape with its vivid expressions of these elements (sharply contrasting forms, colors, and proportions.)

2. Record visual boundaries, whether sharp edges or gradual transitions, which lie between homogeneous landscapes, and are typically related to changes of land form and vegetation.

3. Record lighting effects, giving emphasis or highlighting to particular relationships and patterns of landscape elements. (These tend to occur with low level sun of early morning or late afternoon and make for better photographs.)

4. Record ephemeral effects (Litton 1968), particularly those having to do with weather, the sky, regional climate, and wildlife.

5. Record water in the landscape and the different expressions found in zones dominated by water as well as areas suggesting water presence.

6. Record examples of geophysical structures or processes, such as stream terraces, hogbacks, and strata with related vegetation. These relate to the prime factors in visual landscape sampling, but are not prime factors in themselves.

7. Record settlements, habitations ranging from farmsteads to cities, looking especially at the out-

skirt junctions with the landscape and the collective town site in relation to the broad surrounding landscape.

8. Record examples of impacts which appear in conflict with the adjacent landscape—mining, roads, power transmission, and so on.

9. Record examples of man-made changes (impacts) which appear compatible (or at least tolerable) with the adjacent landscape—agriculture, mining, roads, and so on.

10. To reinforce criterion 1, make photographs and sketches which are representative of the range of visual experiences encountered. When in doubt, take another photograph—too many are better than too few. Sketches may be abstractions or distillations of regionally typical landscapes as well as specific representations.

11. Record and date each photo and sketch in a fieldbook, noting cogent characteristics and any special reasons for making the photo or sketch. Record location using speedometer readings set from an initial point, plot on U.S. Army Topographic maps (1:250,000).

Because ground reconnaissance for a large area is practically limited to viewing from the road, there are necessarily disruptions of observation. These make it difficult to sense the continuity of any landscape subdivision and to see the junctions between dissimilar visual areas. In principle, the objectives of both ground and air observation for landscape inventories are the same. It is appropriate to repeat (with minor modifications) the subject heads and subitems which accompanied the low level air photos so that a comparison may be made with similar ground level photos.

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The Forest Service of the U.S. Department of Agriculture

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The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Litton, R. Burton, Jr., and Robert J. Tetlow

1978. **A landscape inventory framework: scenic analyses of the Northern Great Plains.** Res. Paper PSW-135, 83 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A set of four visual inventories are proposed. They are designed to document scenic resources for varied scales of application, from regional and general to local and specific. The Northern Great Plains is used as a case study. Scenic analysis and identification of criteria extend earlier work. The inventory is based on (1) study of previously developed landscape analysis methods and their terminology; (2) examination of high altitude imagery and topographic maps as sources of visual information; and (3) field observations in the Northern Great Plains. Criteria include visual characteristics and patterns of land forms, vegetation cover, water, and land use.

Retrieval Terms: scenic analysis; landscape inventories; Northern Great Plains.

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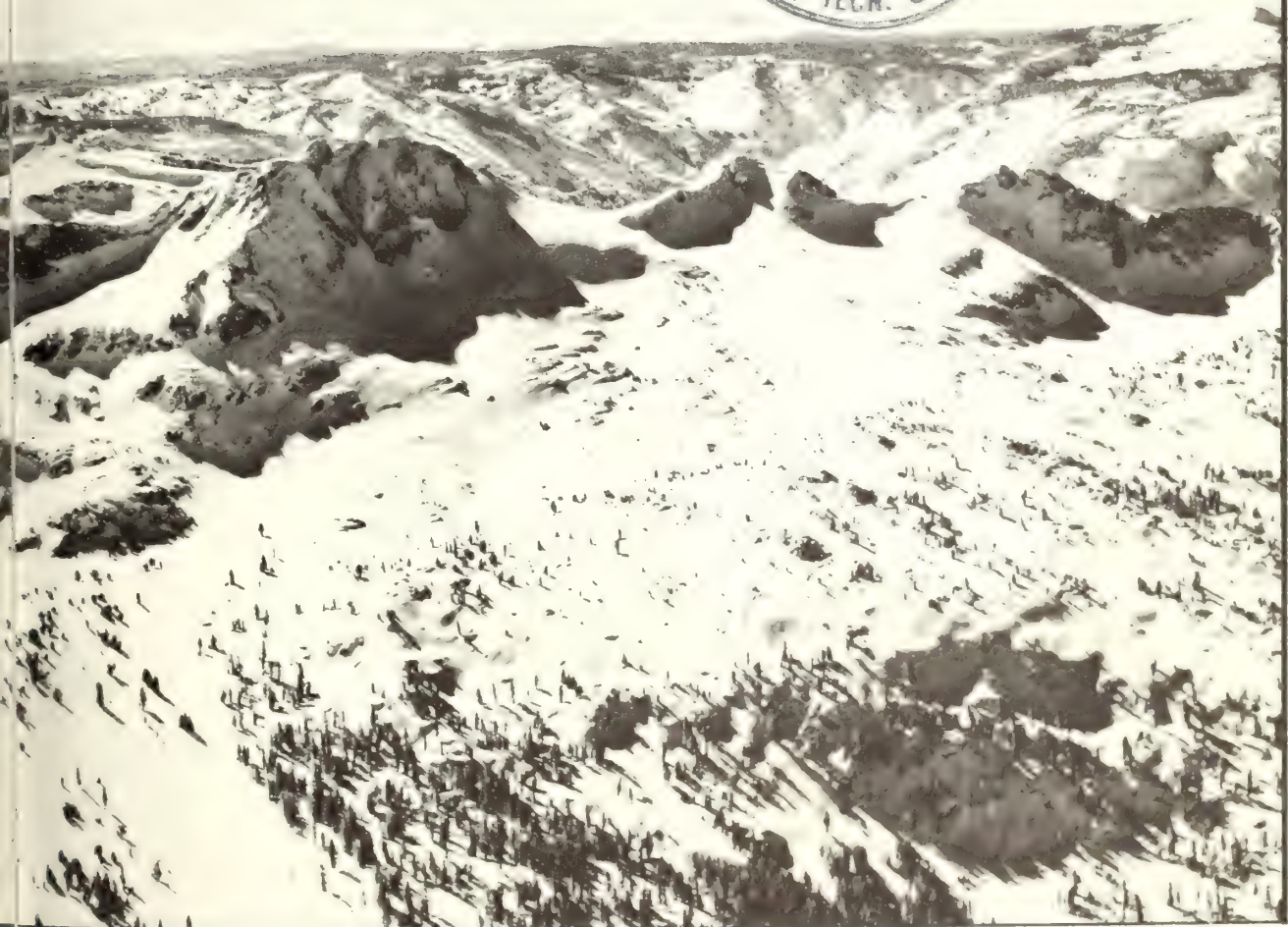
PACIFIC SOUTHWEST Forest and Range Experiment Station

U.S. FOREST SERVICE
DEPARTMENT OF AGRICULTURE

Estimating Snowpack Density From Albedo Measurement

James L. Smith

Howard G. Halverson



The Authors

JAMES L. SMITH, in charge of the Station's environmental hydrology research unit, joined the Forest Service in 1956, and the Station staff in 1963. He is a graduate of the University of Georgia (B.S. degree in forestry, 1948; B.S., in agriculture, 1949; M.F., 1950) and Michigan State University (Ph.D., in hydrology, 1954). **HOWARD G. HALVERSON** was formerly assigned to the Station's snow hydrology research unit, headquartered in Berkeley, Calif. He is now in charge of research on amenities in municipal watersheds, Northeastern Forest Experiment Station, with headquarters in University Park, Pa. He earned degrees in forestry (B.S., Iowa State University, 1960) and watershed management (M.S., 1962, and Ph. D., 1971—both from the University of Arizona). He assumed his present position in 1975.

Cover: The large open meadow at Tioga Pass in the Sierra Nevada, Northern California, is a typical, high-elevation, remote site ideally suited to the requirements for noncontact remote sensing of snowpack characteristics.

Estimating Snowpack Density From Albedo Measurement

James L. Smith

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CONTENTS

	<i>Page</i>
Introduction	1
Snow Density and Albedo	2
Snow Metamorphism	2
Developing Density Prediction Equation	5
Factors Affecting Accuracy of Estimate	7
Attempts to Increase Accuracy of Estimate	8
Discussion	10
Conclusions	12
Literature Cited	13

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IN BRIEF...

Smith, James L., and Howard G. Halverson.

1979. **Estimating snowpack density from albedo measurement.**

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Retrieval Terms: snowpacks; density; depth; water content; measurements; remote sensing; albedo; runoff forecasting.

Snow is a major source of water in the Western United States. Many snowcovered sites are located in relatively inaccessible areas and in Federal wilderness areas. Access is limited to foot travel and remotely operated telemetered snow sensors are not permitted. In such areas it is impossible with the use of conventional methodology to obtain the data necessary for accurately predicting the quantity of available water. A non-contact remote sensing technique is needed to assess snow-water content in such inaccessible areas.

Snow depth can be estimated from aerial snow markers. But measurements of snow density are needed as well for estimating the water content of a snowpack.

A method has been developed for estimating average snowpack density by measuring solar albedo at the survey site when latitude, date, and type of precipitation in the latest storm are known. If the two values—snow depth and snow density—are known, the water content of the pack can be estimated. And the data can be used to forecast water supply.

The method was tested in a study at the U.S. Forest Service's Central Sierra Snow Laboratory, at Soda Springs, California. The Laboratory lies on the west side of the Sierra Nevada, at 2100-m elevation.

Albedo was measured 1 m above the snow and the values were correlated with those of snow density. After five snow seasons, the results showed that 90 percent of the 629 snow density estimates had an accuracy equal to that obtainable by measuring snow density with the conventional gravimetric sampler.

In the study, average snowpack density was correlated with these factors: character of last precipitation event, elapsed time since last precipitation, time of year expressed as solar declination, zenith angle, and the albedo of the snowpack at the time density was measured.

The results were used to develop predictive equations with which density can be estimated from ground-based albedo measurements when it is combined with the factors just listed. The equations can be used to estimate snow density from aircraft-mounted sensors. Although the data reported in this paper were not recorded by aircraft-mounted sensors, other studies suggest that snow albedo measured from an aircraft is closely correlated to that measured by ground-based pyranometers. Measuring albedo by remote sensing techniques makes it possible to estimate snow-water content of inaccessible mountain areas. And it can be done at reasonable cost. Another advantage is that it increases the accuracy of streamflow estimates of water emanating from snowpacks in the areas.



Figure 1—About 75 percent of the currently used snow survey sites above 2750 meters in California are in designated statutory wilderness areas.

The growing need for more water demands more precise techniques of forecasting water yield than can be achieved by using current practices. In the Western United States, snow is a major source of water. Snow courses provide data on snow depth and average snowpack density. These data are used in mathematical models for predicting water supply. Snow data can be collected directly or remotely. They can be obtained by remote sensing techniques—data are telemetered by electronic sensors. To obtain data directly, scientists and technicians travel to the site. Regardless of the method used, data must be obtained from an array of sites covering many different aspects, cover conditions, and elevations. Consequently, the cost of obtaining the data needed for estimating snowpack depth and density is highly prohibitive.

In California, about 75 percent of the snow survey sites above 2750-m elevation now used to collect data are in designated “statutory” wilderness areas (*fig. 1*). Travel in these areas is restricted to foot transportation in all but the few cases where mechanized vehicles were allowed before a wilderness was designated and usage has been permitted to continue.

What is needed is a method of estimating the water content of a snowpack quickly, accurately, and economically from many points in inaccessible locations. Such a method requires that data be collected by remote means. If we can now measure snow depth remotely and measure snow density as well, we can estimate the water content of a snowpack.

We know of only one non-contact method by which snow density might be remotely estimated from deep snowpacks. And that is by measuring albedo from the air. If albedo measurements can be correlated with snowpack density, then we should be able to estimate density remotely. But a correlation must first be established between albedo and average snowpack density from ground-based observations. If such a correlation can be established, it could then be tested by measuring albedo remotely and comparing measurements with those obtained concurrently on the ground.

Some earlier studies have investigated the relationship between albedo and density. Dunkle and Bevans (1956) reported that solar radiation penetrates the top layer of the snowpack in significant amounts—to a depth of perhaps 15 cm, with maximum penetration of

1 m. Solar reflectivity—albedo—is an integrated measure of grain size and water content in the first several centimeters of the snow cover (Giddings and La Chappele 1961). Dunkle and Bevans (1956) found that reflectance and transmittance of snow could be used to correlate albedo with the physical characteristics of snow. Mellor (1965) studied the extinction coefficients of visible light (0.4 to 0.7 μm) through snow as related to density, grain size, and wavelength and concluded that remote sensing might be used to detect subtle differences within a snowpack since the magnitude and wavelength of reflectances vary with snow type.

Bergen (1970, 1971) found a relationship between the extinction coefficient and snow density and grain size. His results agree with the correlation among snow transparency, air permeability, and density which is suggested in the model of Dunkle and Bevans (1956). Bohren and Barkstrom (1974) found that less than 5 percent reflection takes place at the ice grain interface

and that most of the radiation is internally transmitted. Thus, remote observation of the pack is affected by the internal structure of the snowpack. O'Brien and Mur (1975) found that the combination of densification and increased particle size, a result of maturation, reduced the reflectance of snow in relation to the density increase. Mil'kis (1956) published equations and nomograms for estimating snowpack density and albedo for known elevation and date. While density was used merely to characterize the snow, it was possible with his formulae to estimate density if one knew the albedo.

This paper reports a study of albedo measured 1 meter above the snow and the correlation of these measurements with snowpack density. The study was done at the U.S. Forest Service's Central Sierra Snow Laboratory at Soda Springs, California. The findings have application for developing a method for remote sensing of snow density.

SNOW DENSITY AND ALBEDO

Snow Metamorphism

Snow metamorphism in the Pacific Coast Snow Province is largely the result of surface melt percolating through the pack, or rain falling onto the snowpack, or both (Smith 1974). The snowpack matures by layers. Because of this layered maturation, no gradual density increase from the snow-air to snow-ground interface is found as it is in the snowpacks of the midcontinent mountain ranges. In these ranges, there is a general increase in average snowpack density with depth and length of season which is not so evident in the Pacific Coast snowpacks.

Snow density at the Central Sierra Snow Laboratory during the past 24 years has shown these ranges:

Range of average snowpack density

	<u>Maximum</u>	<u>Minimum</u>
	Gm cm ⁻³	
Month:		
November	0.15 to 0.39	0.07 to 0.26
December	.25 to .47	.09 to .26
January	.31 to .43	.14 to .31
February	.25 to .56	.18 to .38
March	.37 to .50	.10 to .43
April	.31 to .54	.19 to .43
May	.39 to .60	.26 to .49
June	.48 to .65	.41 to .52

Snowpack depths over the same period have shown these ranges:

	<u>Range of snow depth</u>
	Cm
Month:	
November	0 to 38
December	0 to 300
January	8 to 505
February	10 to 566
March	10 to 627
April	0 to 546
May	0 to 432
June	0 to 173

Except for the first major snowfall, melt and water loss from snowpacks we have studied originated at the surface and moved downward through the pack. Sizeable quantities of melt water flowed by the end of January in each year between 1966-1967 and 1971-1972 (table 1). During these 6 years, melt water drained from the pack in 21 of the 24 months during the December-March period. More than 2.54 cm of water were released in 18 of these 24 months. And more than 7.62 cm were released in 14 of the 24 months.

The effect of so much snowmelt and water movement through the pack is to "mature" the lower layers of snow early in the season. With maturation, snowpack average density frequently reaches 0.40 gm cm⁻³. During the years 1966-1967 through 1971-1972, this density was reached as early as January and in each succeeding month through May.

Table 1—Months in which melt water drained from snowpacks of the Sierra Nevada of California equaled the amounts shown before April 1, during the 6 years, 1966-67 to 1971-72¹

Month	Melt water					
	<2.54	2.55 to 5.08	5.09 to 7.62	7.63 to 10.16	10.17 to 12.70	>12.71
	Cm					
December	2	1	0	0	1	0
January	0	1	0	2	0	3
February	1	1	0	1	0	2
March	0	0	1	0	0	5

¹Excludes drainage induced by rainfall.

The pack does not have to reach an average density of 0.40 gm cm^{-3} for melt to occur. On April 15, 1968, at three study sites in the open and under forest cover, the pack reached average maximum density of 0.322, 0.323, and 0.348 gm cm^{-3} . In January and February, a "mist-type" rain fell on these packs for parts of 3 successive weeks. Maximum air temperatures ranged from 1.10°C to 2.75°C , with minimum temperatures of from -8.35°C to -2.2°C . After the rain, density averaged 0.30 gm cm^{-3} , and the pack had fully matured to a spring-melt condition. Subsequent snowfalls did not materially compress this pack. Sizable amounts of water moved from this pack each month, and the entire pack melted without any layer ever reaching 0.40 gm cm^{-3} . We measured layers within the pack that matured and melted at the end of snow season without exceeding a density of 0.23 gm cm^{-3} (Smith and others 1970).

"Warm snows"—those in which the snow is isothermal all season—increase in density by compression and water absorption (fig. 2). Usually, as each layer of the pack is successively compressed, the proportion of small pores increases and the layer absorbs all the water it can hold. Additional snowfall further increases the small pore content of the snow, thereby increasing its water holding capacity. Finally, strength increase and structural changes related to maturation prevent further compression. Ice lensing, snow bridging, and other formations that produce loadbearing layers protect lower snow layers from further compression.

The rate of density increase appears to depend on temperature and is not linear. The snowpack densifies rapidly just after a storm, then continues to densify at a reduced rate for several days (Bader 1962). Rates of density increase are altered by general weather conditions, precipitation type, aspect, elevation, wind, total

snow present, snowmelt, and the time of the snow season. Some elements which affect snow densification, such as air and snow temperature, surface snowmelt, wind, and precipitation type (rain or snow), also alter albedo.

Snow density generally increases with time from the beginning of the snowpack in the dry, light density, "cold" snowpacks of midcontinent. Therefore, reasonably accurate estimates of average density may be made by correlating density with time. This estimate should be more accurate than that for wet snowpacks of the Sierra Nevada. In the Sierra Nevada, where the packs are subject to maturation, melt, and water loss in any month during the snow season and may reach maximum density at any period—even in December—a system of density estimation is needed which avoids many of the shortcomings of the historical time-density relationship system (fig. 3). A density prediction system for use in the Sierra Nevada must be dynamic enough to allow for the variances just enumerated. Such a system would need to incorporate albedo-density changing parameters into its equation. In general, conditions which favor rapidly increasing density reduce albedo. For example, rain-on-snow increases density and decreases albedo. New snow decreases average density and increases albedo. Albedo of new snow in early season will degrade at a slower rate than that falling in May or June.

We reasoned that a correlation might exist between average snowpack density and albedo and other variables. Average snowpack density would be the dependent variable; albedo, type of precipitation in the last storm, date and time of measurement, zenith angle, and number of days since the last storm would be the independent variables. We would test to develop a correlation between average snowpack density and

Figure 2—A 7-inch rain, beginning January 17, 1969, fell on a 78-inch deep snowpack. All the rain was absorbed by the pack. The rain and new snowfall between January 17 and January 30 produced density increases ranging from 0.05 gm cm^{-3} to 0.25 gm cm^{-3} .

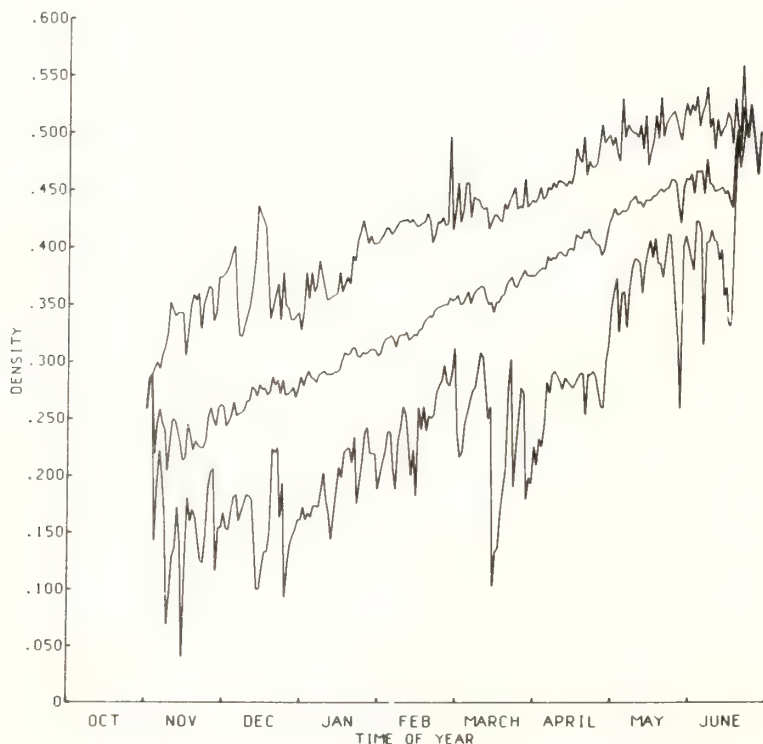
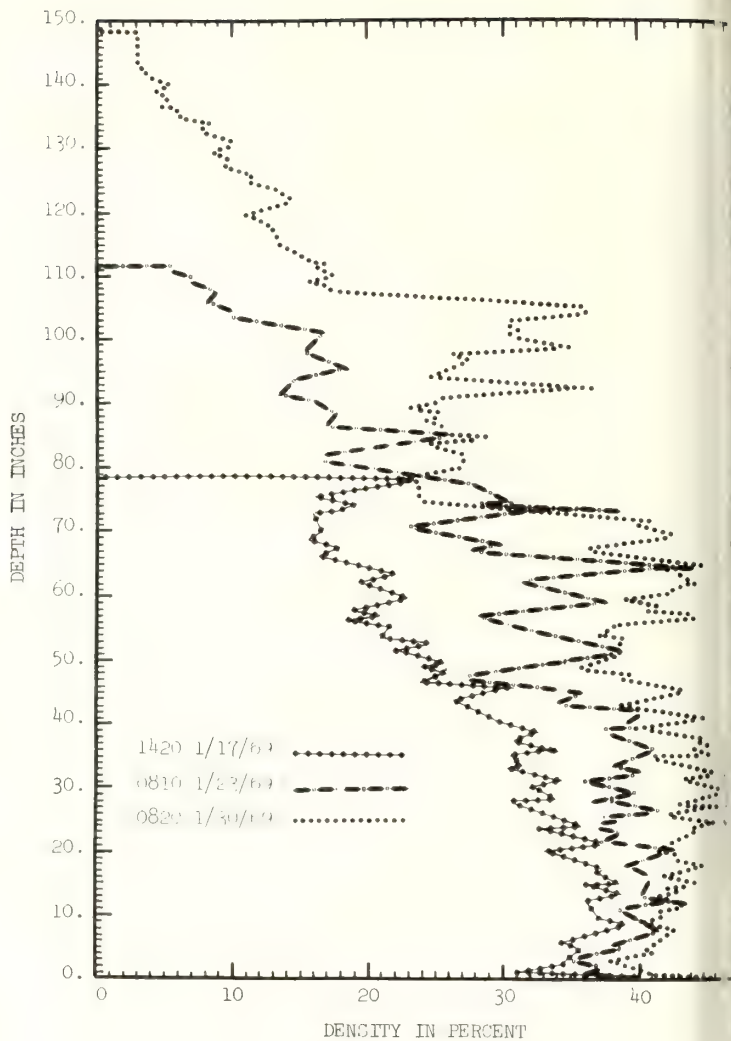


Figure 3—Snow density varies as a result of precipitation, temperature, and snowpack regime for each day. Although density increases in a linear fashion with time, the amount at any particular moment may be above or below the mean line as a result of new rain, compression, and other variables.



Figure 4—At the Central Sierra Snow Laboratory, Soda Springs, California, daily snow density profiles, precipitation, relative humidity, snow, air, and soil temperatures, dew point, windspeed, direction and amount of air flow, and long-wave and short-wave solar radiation are automatically sensed at predetermined intervals.

each of the independent variables. Correlation data would then be used to derive an equation for predicting snow density.

Developing Density Prediction Equation

Data on albedo and average snowpack density were collected at the Central Sierra Snow Laboratory, at Soda Springs, California (*fig. 4*). Measurements were recorded for the snow seasons 1967-1968 through 1971-1972. Average snow density and concurrent snow albedo were measured daily for the five seasons. For this study we selected 629 pairs of measurements.

Measurements recorded on some days during each of the five seasons were excluded from the study: days following precipitation of less than 7 mm water equivalent and days when snow density measurements were not recorded. Measurements were begun after the snowpack reached 60-cm depth in early season and were ended when the spring snowpack had melted to this depth, since albedo can be influenced by the character of the underlying soil to a depth of less than 60 cm.

The dependent variable, average snowpack density, was measured with an isotopic profiling snow gage

(Smith and others 1972). The gage measures snow density in approximately 1-cm intervals from the soil surface to the air-snow interface. Average snowpack density is the average of all increments in the snowpack. Density determinations by this method have a standard error of about 0.01 gm cm^{-3} .

At one site at Central Sierra Snow Laboratory we periodically measured albedo and snow density at the same time. Type of precipitation was recorded for each storm. To measure albedo we used two Eppley pyranometers¹—one mounted in the normal position and the second inverted. The plane of the pyranometers was set parallel to the snow surface and 1 m above it. The pyranometers were read sequentially, first the upward-facing instrument followed about 2 seconds later by the inverted. Decimal albedo was measured at 30-minute intervals for 3 hours before and after density determinations, limited by times of sunrise and sunset.

New snow is usually less dense than existing snowpack. The rate of new snow densification and the density of the existing snowpack yield different values, depending on the time of the snow season when measurements are taken. Late season snowpacks are usually

¹ Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

more dense than early season packs, and new snow metamorphosis proceeds faster in late season. Because the snow season spans 2 years in the northern hemisphere, calendar date is a difficult variable to use.

Date can be expressed as solar declination, the angular displacement of the sun north (+) or south (-) of the celestial equator. Solar declination reaches a minimum value, -23.45° on December 22, and a maximum of $+23.45^\circ$ on June 22. Solar declination can be determined from an "Ephemeris of the Sun" at 4-day intervals (List 1958), or it can be approximated by the equation:

$$SD = -23.45 \cos [(DTNO + 10.5) * 360/365.25] \quad (1)$$

in which

SD = solar declination, degrees

DTNO = day number of the year (Julian Date)

recalling that the algebraic signs of cosine are:

$$\begin{array}{cccc} 0^\circ-90^\circ, & 90^\circ-180^\circ, & 180^\circ-270^\circ, & 270^\circ-360^\circ \\ + & - & - & + \end{array}$$

The type of precipitation affects the average density of the resulting snowpack. Winter precipitation may not be all snow; it may be all rain, or rain and snow mixed. A rain-on-snow event results in rapid declines in albedo and rapid increases in density. Because of different types of precipitation, storms were coded by a classification scheme into three groups: snow only, mixed rain and snow, or rain only and were then assigned the value 0, 0.5, or 1.0, respectively.

The reflectivity of many surfaces is a function of the incident angle of radiation. Snow shows a weak, but significant, albedo change with incident angle (Mellor 1964). New snow reflectivity is more sensitive to the incident angle of radiation; old snow surfaces are less responsive (U.S. Army 1956). With solar radiation, the angle of incidence is described by the zenith angle (Z) of the sun, where Z is the angular displacement of the sun from vertical at the site. The zenith angle changes during the day, reaching 90° at sunrise and sunset over a level surface, and declining to a minimum at solar noon. The minimum is always equal to the algebraic total of latitude minus solar declination. At intermediate times, the zenith angle can be computed by:

$$ZCOS = \sin(L) \sin(SD) + \cos(L) \cos(SD) \cos(h) \quad (2)$$

in which the undefined terms are:

ZCOS = cosine of the solar zenith angle

L = site latitude, degrees

h = hour angle, degrees

The hour angle (h) is the number of hours before or after solar noon when the zenith angle is to be computed. It is assigned a value of 15° per hour because the earth turns 360° in 24 hours, or 15° per hour. Time, as solar time, must be used to compute the hour angle.

The time of measurement is converted to true solar time by a two-step process. First, 4 minutes is added to local standard time for each degree of longitude the snow course is east of the time zone meridian, or 4 minutes is subtracted for each degree west. Second, the equation of time for the measurement date is algebraically added to the result of the first step (List 1958).

Several relevant variables are combined into a functional expression:

$$RHO = f(A, SD, D, R, ZCOS) \quad (3)$$

in which the undefined terms are:

RHO = average snowpack density, decimal

A = albedo, decimal

D = days since cessation of storm, integer

R = proportion of rain to snow in last storm: 0, 0.5, or 1

The final form of the equation was derived by a combination of regression and graphical techniques. Regression techniques are designed to find the mathematical function that best describes the relationship between the dependent and several independent variables. The general linear model for our purposes is:

$$RHO = b_0 + b_1A^2 + b_2SD + b_3D + b_4R + b_5ZCOS + E \quad (4)$$

in which the undefined terms are:

E = error, gm cm^{-3}

b_j = the regression coefficients to be estimated.

Initial graphic analysis showed that albedo was, as expected, the best single predictor of average snowpack density, but the relationship was not linear. The square of decimal albedo showed better fit and was adopted for future analyses.

Regression analysis by the least squares technique was done and regression coefficients and their significance tabulated (table 2). The t-test values showed that each variable was significant at the 99 percent level.

The final form of the equation is:

$$RHO = 0.452 - 0.123A^2 + .003(SD) + .002(D) + .027(R) - .039(ZCOS) + E \quad (5)$$

The multiple correlation coefficient (R^2) is 0.68 and the standard error of estimate equals 0.037 gm cm^{-3} .

As with any relationship developed through linear regression techniques, there is an error associated with the predicted variable. The standard error in this work where we used all 629 data points is 0.037 gm cm^{-3} , or 3.7 percent density. According to Work and others (1965), the Federal Slotted Sampler overmeasures water equivalent by from 7 to 12 percent. The Federal Slotted Sampler, which has been used universally in snow surveying for the past 40 to 50 years, extracts gravimetric samples of snow from which density and water content are computed. Because of the influence of depth it is difficult to convert errors in snow-water equivalent to errors in density; however, it appears that snow density measurements are high by about 0.04 gm cm^{-3} .

Factors Affecting Accuracy of Estimate

Classification by Error Class

Because of the low multiple correlation coefficient ($R^2 = 0.68$), we analyzed the 629 pairs of albedo-density measurements used in the study to determine when the density estimation was most accurate and

under what conditions it was least accurate. The density error associated with the Federal Slotted Sampler is about 0.04 gm cm^{-3} with an undetermined error distribution. To be useful, any complementary system should at least approach this accuracy. We apportioned the 629 sets of data points into three classes depending upon the difference between measured and estimated density for each point:

- Class I Error of estimate $<0.04 \text{ gm cm}^{-3}$
- Class II Error of estimate ≥ 0.04 to $<0.07 \text{ gm cm}^{-3}$
- Class III Error of estimate $\geq 0.07 \text{ gm cm}^{-3}$

Four hundred sixty-six (466) of the 629 data points (74.09 percent) fell within Class I accuracy; Class II accuracy contained 110 (17.49 percent); and Class III contained 53 (8.43 percent) of the 629 data points. Because the error of estimate of 25.92 percent of the 629 samples was greater than the average error attainable with the Federal Slotted Sampler, we subdivided the data several ways in an effort to determine the conditions under which errors arose.

Error and Year of Measurement

Analyses were made to determine the relationship between year and error (table 3). A wide range of

Table 2—Linear regression coefficients and variable ranges used to estimate average density by the equation $RHO = b_0 + b_1A^2 + b_2SD + b_3D + b_4R + b_5ZCOS + E$

Coefficient	Variable	Value	T_b	$T_{\alpha=.05}$	$T_{\alpha=.01}$
b_0	constant	0.452	35.37	1.96	2.58
b_1	A^2	-0.123	-8.62	1.96	2.58
b_2	SD	0.003	17.45	1.96	2.58
b_3	D	0.002	8.44	1.96	2.58
b_4	R	0.027	6.87	1.96	2.58
b_5	ZCOS	-0.039	-3.01	1.96	2.58

and Degrees of freedom = 623
 $R^2 = 0.68$
 Standard error of estimate = 0.037 gm cm^{-3}

Variable	Maximum	Minimum	Average
RHO	0.466	0.211	0.375
A	1.00	0.314	0.674
SD	20.94	-23.45	-6.53
D	27	0	8
ZCOS	0.948	0.149	0.570

^aT-test values showed each variable was significant at the 99 percent level.

Table 3—Sample points by years to determine relationship between error and year of measurement

Year	Sample points	Error of measurement (gm cm^{-3})		
		Class I <0.04	Class II 0.04 to 0.07	Class III ≥ 0.07
1967-68	33	12	12	9
1968-69	24	20	4	0
1969-70	205	128	52	25
1970-71	189	185	3	1
1971-72	178	121	39	18
Total	629	466	110	53

accuracy between years, from almost perfect accuracy ($<0.04 \text{ gm cm}^{-3}$) between measured and estimated density in 1968-1969 and 1970-1971, to a lower level of prediction accuracy in other years was evidenced. In 1967-1968, with only 33 sample points, our accuracy was quite poor.

Precipitation Type

To assess the effect of precipitation type upon the accuracy of density estimates, we subdivided the data into the three classes based on the type of precipitation in the last storm before the measurement (*table 4*).

Greatest accuracy was achieved when we measured albedo after mixed rain-snow or rainstorms. Greatest error occurred when measurements were taken after snowstorms. Ninety to 95 percent of all measurements taken after rain or mixed rain-snow events fell within the $<0.04 \text{ gm cm}^{-3}$ density error range, while only 66 percent of those taken after snowstorms fell within this density error class. This is to be expected, since albedo is a surface phenomenon and recent snowstorms will inflate its value.

Elapsed Time Since Last Storm

To test further the effect of new snowfall upon the accuracy of the density estimate obtained, we divided the data into accuracy Classes by years and the number of days elapsing between the storm event and albedo measurement (*table 5*). Measurements made more than 10 days after the end of a storm were the most accurate.

Month of Measurement

Although late season measurements have an overall improved accuracy over early season measurements, Class II and Class III accuracies can occur in any month (*table 6*). Errors are not related to time of measurement, but are related to anomalies in albedo resulting largely from recent snowfalls.

Attempts to Increase Accuracy of Estimate

Because of technical problems with the electronic system at the Central Sierra Snow Laboratory in 1967-1968 and 1968-1969, we could use only 33 and 24 data points, respectively, from each of those years. Further, the data from 1967 to 1969 were not evenly distributed through the winter season. These data did not provide us with an adequate array of seasonal conditions; consequently, we decided to delete them from this phase of the analysis.

Available data points for each of the remaining years ranged from 178 to 205. Nineteen of these remaining data points had errors in excess of two standard deviations. We examined these points along with all the others for the years 1969-1970, 1970-1971, and 1971-1972 to determine the reason for the large errors. We found that on all 19 days there was the possibility that the upright Eppley was covered with snow. Light snowfalls were occurring at the time of measurement. The 19 data points were removed from the analysis, along with the 57 points from years 1967-1968 and 1968-1969. In all, 76 data points were removed from the data base of 629 points.

We then analyzed the other data points to determine the effect of cloud cover on albedo correlation (McMillan and Smith 1975). Ambach (1974) pointed out the effect of cloud cover upon the radiation balance over snow. Fritz (1955) noted the uniformity of diffuse radiation over snow cover under overcast skies. Of the original 629 sets of concurrently obtained albedo and snow density measurements, 553 pairs were divided into three sets of data based on cloud cover at the time of measurement.

0.0 to 0.2 cloud cover = clear

0.3 to 0.7 cloud cover = partly cloudy

0.8 to 1.0 cloud cover = overcast

Table 4—Accuracy classes as opposed to type of precipitation in the last storm before measurement

Year	Samples	Precipitation type								
		Snow			Mixed rain and snow			Rain		
		Classes			Classes			Classes		
		I	II	III	I	II	III	I	II	III
Number of points by accuracy classes										
1967-68	33	12	12	9						
1968-69	24	14	4	0	6	0	0			
1969-70	205	123	44	25	5	2	0	0	6	0
1970-71	189	80	1	1	13	1	0	92	1	0
1971-72	178	72	39	18	3	0	0	46	0	0
Total	629	301	100	53	27	3	0	138	7	0
Percent of totals for each group		66.3	22.0	11.7	90.0	10.0	0	95.2	4.8	0
Total number for each precipita- tion type			454			30			145	

Table 5—Accuracy of estimate classes, by number of days since last storm

Year	Points	0 to 3 days			4 to 9 days			10 to 27 days		
		Classes			Classes			Classes		
		I	II	III	I	II	III	I	II	III
1967-68	33	0	0	2	2	11	7	10	1	0
1968-69	24	14	0	6	6	4	0	0	0	0
1969-70	181	9	27	36	36	20	13	83	5	2
1970-71	189	84	1	43	43	1	0	58	1	0
1971-72	178	28	7	49	49	31	0	44	1	0
Total	629	135	35	136	136	67	20	195	8	2

Table 6—Effect of time of year upon accuracy of estimate given in percent of total number of points obtained per month, by accuracy classes

Year	December			January			February			March			April			May		
	Classes			Classes			Classes			Classes			Classes			Classes		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Percent																		
1967-68	14	79	7	91	9					100								
1968-69				60	40		100									100		
1969-70						9	55	37		4	16	1	98	2				
1970-71	100			100		98	2		100				93	4	4	97	3	
1971-72		76	24	94	6	100			100				8	57	36			
All years	31	56	13	93	7	61	24	15	86	9	5	66	21	13	97	3		

The equation derived with all three cloud conditions with variables listed in their order of significance is:

$$\text{RHO} = .00323\text{SD} + .00193\text{D} + .0279\text{R} - .0756\text{A}^2 + .412 + \text{error} \quad (6)$$

The multiple correlation coefficient is $R^2 = 0.79$. The standard error of estimate was found to be 0.027 gm cm^{-3} .

When all data were excluded from the analysis except that for overcast conditions, the derived equation was:

$$\text{RHO} = .00325\text{SD} - .123\text{A}^2 + .0334\text{R} + .00145\text{D} + .436 + \text{error} \quad (7)$$

The multiple correlation coefficient for this equation is $R^2 = 0.79$. The standard error of estimate is 0.031 gm cm^{-3} .

DISCUSSION

An empirical relationship between average snowpack density and albedo, and other site and storm variables exists. Under the conditions of our experiment we found that on-site average snowpack density can be estimated from snow albedo measurements taken 1 meter above the snow when general site and storm information is available.

Many circumstances can affect the accuracy of such an estimate. The pyranometers must not be covered with even a thin film of snow or ice. New snow on the surface of the snowpack will, of course, yield higher values of albedo and in some cases decrease the accuracy of the density estimate. Even with the full data base of 629 points and with the possibility of erroneous pyranometer readings for some of the data, 90 to 95 percent of the estimates of density were within Class I accuracy when measurements were taken after mixed rain and snowstorms, and after rainstorms. Even with the possibility of some portion of the data base having erroneous albedo measurements, 66 percent of the estimates of snow density made after snowstorms were within the minimum error class. And, if density measurements were taken 10 days after a snowstorm, then almost all data fell within the minimum error classification.

This work was designed to devise a method to gather accurate snow survey data by remote means. We know that the average error of Federal Slotted Sampler data and density estimates based on albedo are roughly equal. Except for one study (Work and others 1965), however, we know little about the error distribution of snow densities computed from gravimetrically obtained data—a volumetric sample of snow which is extracted from the snowpack. Work and others (1965) showed that with gravimetrically obtained data, error increased as snow-water equivalent increased. Obviously, some of the data obtained from snow surveys includes errors greater than the mean error of 0.04 gm

cm^{-3} . But considering that errors must occur in gravimetric sampling, we can assume that the remote system based on albedo—where most measurements fall within the minimum error class—should yield acceptable estimates.

The albedo method for estimating average snowpack density appears to offer the potential for a method of measuring average density of snowpacks in open areas. Albedo can be measured by aircraft-mounted instrumentation. We suggest that this system of density estimation is useful for increasing accuracy of prediction of streamflow from snowpacks in statutory wilderness and other remote areas.

Snow courses and related instrumentation currently provide the basic snow water equivalent data used in streamflow and flood prediction. Snow survey courses are located in some of the least accessible areas of the western mountains (*fig. 5*). Traditionally, snow sampling is done on foot or by mechanized travel to the snow course, sampling gravimetrically, and returning. Basic sample information includes snow depth, water equivalent, and core length; average snow density is computed from the depth and water equivalent measurements. Because of cost, only a limited number of samples are now obtainable. The suggested system—albedo measurement of snowpack density—would extend the data base.

Wilderness status has precluded mechanized travel to some established snow survey locations. Many snow courses located in existing or planned wilderness areas are essential—they cannot be relocated or eliminated from the water supply forecast model. These essential snow courses may be difficult or dangerous to reach on foot, especially during winter; but pedestrian oversnow travel is normally the only acceptable means of access under the wilderness statutes. Also, there is an increasing need to gather more data from wilderness sites than are currently being obtained.

The alternative to the traditional sampling scheme is to incorporate automated snow gaging or remote sensing to acquire the necessary information. Several instruments have been proposed to gather snow data. Snow water equivalent can be telemetered from pressure pillows (Beaumont 1965) or from an isotopic snow gage measuring nuclear attenuation by the entire snowpack (Gerdel and others 1950). Depth, density, and water equivalent may be obtained with a profiling nuclear snow gage (Smith and others 1972). In the area of remote sensing, the attenuation of natural radiation has been tested, but its use is limited to about 40 cm water equivalent (Bissell and Peck 1974). Owing to the high cost of installation and operation, only a limited number of automated snow gages can be installed in any area. With the exception of natural radioactivity monitoring, installation in statutory wilderness areas is generally prohibited.

The demand throughout the West for improved snow survey accuracy can best be met by increasing sampling frequency and sampling intensity, but at a more reasonable cost than that associated with remote operation of snow sensors. If snow albedo can be

measured from aircraft-borne solar radiometers, these measurements can be related to point estimates from snowpack average density at that site. Snow depth can concurrently be measured from existing aerial snow markers or other systems. Advances in aircraft and satellite remote sensing technology now permit comparisons between ground and remote observations.²

Snow albedo has been measured from aircraft (Bauer and Dutton 1962). While results in this report were obtained from pyranometers mounted 1 meter above the snow surface, we believe that albedo measurements taken from aircraft will be essentially the same as those measured from the ground. Studies at the University of Saskatchewan in which ground-based albedo measurements were compared to airborne measurements gave results which were in close agreement².

Pyranometers mounted on helicopters may be flown within 100 feet of the snow surface with a forward

² Personal communication from D. H. Male, University of Saskatchewan, Saskatoon, Canada, 1975.



Figure 5—This volcano snow course at 3503-m elevation is in the Sierra Nevada, South Fork, San Joaquin River Basin, California.

speed of about 25 miles per hour without affecting the snow cover. At this height the pyranometer reading will not be affected by vegetation alongside the large openings used in snow surveying. The snow surface at the measurement site should be level to prevent differences in albedo caused by slope angle differences or a mathematical adjustment will need to be made.

Operational water supply models of snow survey data are based on empirical relationships. Changing the number and location of snow courses could change the relationship. Measuring a snow course aerially rather than on the ground, however, should have no effect. If extra courses are added, the present proportion of courses in each elevation zone and aspect should be maintained. Unchanged proportion of courses should leave the present water supply model unchanged, but would increase the accuracy of streamflow prediction.

The albedo method is based on an empirical relationship and the several coefficients may need reevaluation if the equation is applied to areas or elevations where the snow maturation process is different from that at the Central Sierra Snow Laboratory.

The correlation established between density and albedo at the Snow Laboratory is most accurate for the

type of snow maturation from which the formulas were developed. It should be expected to work in the warm, wet, deep snows of the Pacific Coast Province. In areas subject to depth hoar (temperature gradient metamorphism) this system would be less accurate.

If the density-albedo system is used, aerial surveys would need to be scheduled at times when greatest accuracy of estimate might be attained: after rainstorms, or more than 10 days following snowstorms. But slightly degraded accuracy can be achieved just after a storm stops. The usefulness of the density-albedo system for aerial surveys can only be assessed after the techniques developed from ground-based research are applied to an aerial reconnaissance.

The studies reported in this paper have been used as the foundation for an aerial test of the proposed new system for density estimation from aircraft. In that study, which is currently underway, albedo is measured from a helicopter and snow density is determined with ground measurement using the profiling snow gage.

The research reported here does not include measurements made from aircraft, but only ground-based measurements to indicate the validity of density estimation from albedo measurement.

CONCLUSIONS

We found a positive correlation between snow density, snow albedo, and other parameters in the Sierra Nevada of California. A predictive equation was developed in which average snowpack density could be estimated with an R^2 of 0.68 and a standard error of 0.037 gm cm^{-3} . The only independent variable measured at the site was snow surface albedo. Additional variables used in the equation are date and time of measurement, zenith angle, number of days since last storm, and type of precipitation in the last storm.

The 629 concurrently obtained data points (snow density and snow albedo) used for the formula development were analyzed to determine under what conditions the formula gave the most accurate results. Of the

629 points, 74 percent had errors of less than 0.04 gm cm^{-3} , the approximate average error of the Federal Slotted Sampler. Of all data taken after snowstorms, 66 percent fell within this error classification, while 90 and 95 percent, respectively, fell into this class when data was taken after rain and after mixed rain-snowstorms. If measurements were made as much as 10 days after a storm, 95 percent of the data points had errors of less than 0.04 gm cm^{-3} . The month in which the measurement was taken had little effect upon accuracy.

This study points out the potential for developing a method for aerial estimation of snow density by measuring snow albedo from aircraft.

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Retrieval Terms: snowpacks; density; depth; water content; measurements; remote sensing; albedo; runoff forecasting.

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Snow is a major source of water in Western United States. Data on snow depth and average snowpack density are used in mathematical models to predict water supply. In California, about 75 percent of the snow survey sites above 2750 meter elevation now used to collect data are in statutory wilderness areas. There is need for a method of estimating the water content of a snowpack in inaccessible locations by remote means. If snow albedo can be measured from aircraft and these measures correlated with snowpack density, we should be able to estimate density remotely. But a correlation must first be established from ground-based observations. This paper reports a study of albedo measured 1 meter above the snow and the correlation of these measurements with snowpack density. The study was done at the Forest Service's Central Sierra Snow Laboratory, Soda Springs, California. The findings have application for developing a method for remote sensing of snow density.

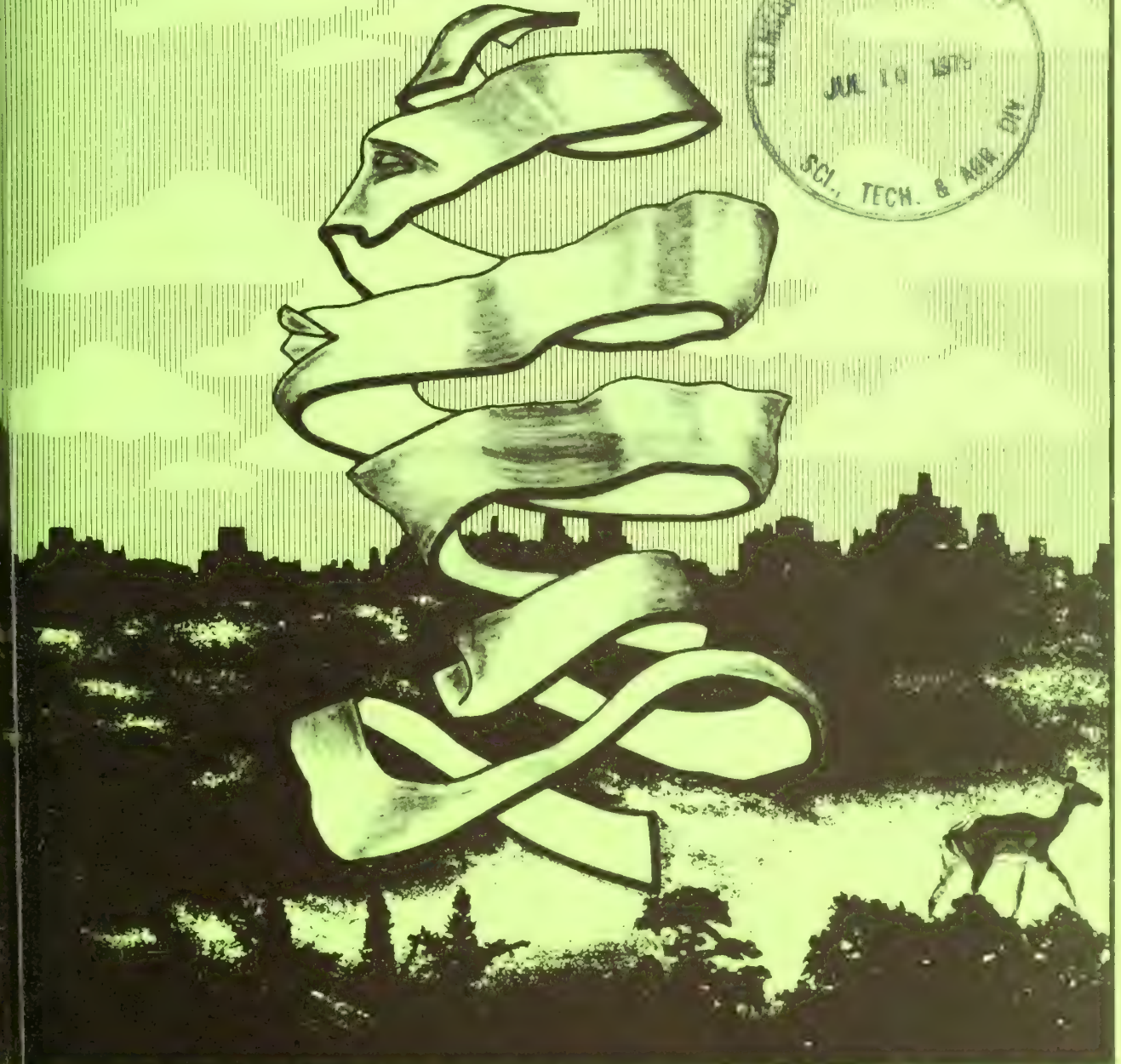
Retrieval Terms: snowpacks; density; depth; water content; measurements; remote sensing; albedo; runoff forecasting.



PACIFIC SOUTHWEST Forest and Range Experiment Station

URBAN USERS OF WILDLAND AREAS as Forest Fire Risks

William S. Folkman



The Author

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Finally, sincere thanks to residents of the Los Angeles and San Francisco metropolitan areas who graciously participated in the survey.

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CONTENTS

	<i>Page</i>
Introduction	1
Methods	3
Results	5
Wildland Use and Wildland Users	5
Wildland Users and Fire Risk	9
Attitude and Knowledge Scores	12
Exposure to Information Sources	13
Discussion	15
Literature Cited	17

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Retrieval Terms: fire prevention; urban visitor; fire risk; knowledge; attitudes; urban visitor characteristics.

Previous studies of the human risk factor in the prevention of wildland fires have focused on rural and small-town populations, which were presumed to contribute disproportionately to fire starts. Prior to this study, the urban population, which provides an increasing number of wildland users each year, has been neglected.

By means of a random-digit-dialing telephone interview survey, approximately 700 wildland visitors were reached in the Los Angeles-Long Beach and San Francisco-Oakland Standard Metropolitan Statistical Areas of the 1970 U.S. Census. Limited data were also obtained from an additional 800 households, none of whose members had visited wildland areas. Interviews were completed with 86.6 percent of all households reached.

The research objectives of the study were (1) to determine the prevalence of wildland use by residents of the two metropolitan areas, the reasons for non-use, and the characteristics of users; (2) to describe and analyze the activities, knowledge, and attitudes of urban visitors of wildland areas that may contribute to their fire risk; (3) to assess selected communication channels for conveying forest fire prevention information to the residents of metropolitan areas.

Fifty-three percent of the San Francisco households and 40 percent of the Los Angeles households contained adult members who had visited a wildland area in California in the previous 2 years. Differences in socioeconomic characteristics between visitor and nonvisitor households were quite marked. The reason most respondents gave for not visiting was simply that they preferred to do other things. Economic reasons were seldom mentioned, but the characteristics of the households suggest that this factor may be significant.

The median length of time spent in wildland areas within the span of one year by those making such visits was between 7 and 8 days. About half the visitors reported that their most recent visit required a drive of 2 or more hours from their residence.

Although direct comparisons are not possible, urban wildland visitors appear to be as knowledgeable

as rural residents about fire characteristics and fire prevention precautions. There are some serious gaps in their knowledge, however.

A number of sets of statements were used in the interviews to determine the attitudes presumed to relate to fire risk. In general, wildland visitors showed positive attitudes toward protecting the natural resource and also toward the forestry agencies responsible for wildland management. Attitude and knowledge scores did not vary greatly with the frequency or type of wildland experience, nor with differences in demographic and other background characteristics of the visitors.

More than half of the respondents recalled having been exposed to a fire prevention message within the previous month or so. The most frequently recalled source for such a contact was television; billboards were next in frequency. Radio was seldom mentioned. Fire prevention messages channeled through voluntary organizations concerned with wildland use or conservation would reach only 10 to 15 percent of urban wildland visitors. Those who were personally handed lists of rules were more likely to read them than were those who merely saw them posted.

This study makes it clear that there is no sharp distinction between those who represent high fire risk and those who constitute little or no risk. On the basis of our criteria, however, young, single males from lower or low middle socioeconomic levels do appear to represent higher than average risk. To a somewhat lesser extent, so also do older, retired persons.

In general, it is apparent that people in all walks of life are aware of the forest fire problem and are in favor of fire prevention efforts. But we still have a high incidence of fire of human origin. Therefore, aside from normal procedures to maintain favorable attitudes, future efforts should be concentrated on filling the gaps in the public's knowledge of appropriate behavior in fire-fragile wildlands, and, most importantly, on assuring that these attitudes and understandings are expressed in changed behavior.



The escalating demands on the limited natural resources of our wildland areas have become, justifiably, a national concern. The inadequacies of our future timber supply, the need for plentiful clear water, and the burgeoning demand for wildland recreation facilities all accentuate the need for prudent, informed, and well-planned management of our wildland areas.

A primary responsibility of wildland management is to minimize losses from fire. By their very nature, most wildlands, such as forests, brushlands, and grasslands, contain vast accumulations of highly combustible vegetation; the increasing numbers of recreational visitors represent increasingly numerous sources of potential ignition. The result is increasing fire risk, threatening valuable timber resources, protective watershed cover, and recreational lands. As dramatically demonstrated every year or two, each fire start is potentially a major disaster, and even when the fires are of smaller magnitude they destroy not only natural resources but private property, and even human lives.

Fire prevention is a primary aim of both Federal and State agencies. Prevented fires do not require expensive fire suppression efforts nor do they entail losses to natural resources, private property, or human lives.

This study is part of the continuing research program of the Wildfire Prevention Research Work Unit of Pacific Southwest Forest and Range Experiment Station, conducted in cooperation with the California Department of Forestry over a period of years. Since the great majority of forest fires are the result of human carelessness, the activities of this work unit have focused on research into the behavioral aspects of fire prevention. Previous work (Folkman 1965, 1973) has concentrated on rural and small town populations residing near forest areas, which were presumed to contribute disproportionately to forest fire starts (Chandler 1960). Mounting evidence now suggests that visitors from metropolitan areas are becoming a more important source of fire starts as the number of visitors from these areas continues to

grow. To shape more effective forest fire prevention policies and programs, information is now required on wildland users from metropolitan areas—information comparable in coverage and detail to that already available on local populations. The telephone interview survey reported here was directed toward filling this need.

The focus of the study was on visits to California wildlands by residents of the State's two largest metropolitan areas, the Los Angeles-Long Beach and the San Francisco-Oakland standard metropolitan statistical areas. Together, these two metropolitan areas contain approximately half the residents of the state.

The setting is an appropriate one. The greater part of California is covered by wildlands, including major forests, and the extended dry season presents serious fire hazards throughout most of the summer and fall. In addition, many of the State's metropolitan residents enter these wildland areas for day use and more extended recreational visits. Hiking and camping in nearby regional parks are especially popular with residents of the San Francisco area, while Los Angeles County is bordered on the north, east, and south by National Forests providing recreational areas for day use. Residents of both areas also make extensive vacation use of wildlands farther from their homes.

The study had three major objectives, each defined by a series of interrelated research questions.

The first objective was to explore the extent of wildland use, the reasons for non-use, and the characteristics of users, on the following basis:

1. What proportion of households of major California metropolitan areas contain members who make use of wildland areas, to the extent of at least one visit to such an area in California within the past 2 years?
2. When no member of a household makes use of wildland areas, is the main reason personal preference, or constraints related to lack of transportation, economic level, or other conditions?
3. How do wildland use and the reasons for non-use vary by household demographic characteris-

tics, place of residence, socioeconomic level, and ethnic identification?

The answers to these questions should provide an indication of the number of urban users of wildland areas, the segments of the urban population from which they are drawn, and probable influences on the volume of their wildland use in the future.

The term "wildlands" is used in a restricted sense throughout this report. The study concentrated on visits to forests, brushland, and grassland areas, where fire prevention is most needed. Deserts and seashore areas were not dealt with, even when officially designated as wildlands, as they generally do not contain major concentrations of flammable vegetation.

The second objective was to describe and analyze the activities, knowledge, and attitudes of urban visitors to wildland areas as contributing to fire risk, as follows:

1. How much and what types of use do urban visitors make of wildland areas, especially as to use of fire in back country areas, where fire starts are less easily detected?

2. How knowledgeable are urban visitors regarding (a) seasonal and weather conditions as fire hazards in wildland areas; (b) the role of human carelessness in forest fires; (c) the meaning of fire safety regulations; (d) fire safety practices; and (e) related information about forest fires?

3. How salient are the concepts of forest fires and fire prevention to urban visitors to wildland areas, and what attitudes do such visitors hold toward (a) the seriousness of forest fires; (b) rules and regulations in wildland areas and their enforcement; (c) government agencies responsible for wildland areas; and (d) persons who may or have caused fire through carelessness?

4. How do fire prevention knowledge and attitudes vary with (a) the frequency and type of wildland use; (b) place of residence; and (c) demographic and other background characteristics of the visitor?

Answers to these questions help identify types of visitors and situations presenting the greatest fire prevention risks; they also aid in pinpointing areas of knowledge, awareness, and opinion to which fire prevention programs may be most effectively addressed.

The third objective was to assess selected communication channels for conveying forest fire prevention information to the residents of metropolitan areas, as follows:

1. What proportion of urban visitors recall seeing lists of rules and regulations distributed or posted in wildland areas?

2. What proportion of urban visitors recall recent exposure to forest fire prevention messages in the mass media?

3. What proportion of urban visitors belong to national or statewide voluntary organizations with interests in wildland use?

4. How does exposure to these communication channels vary with fire risk, with place of residence, and with demographic and other background characteristics of visitors?

Answers to these questions aid in choice of appropriate and effective channels for fire prevention educational and public relations programs. It should be noted, however, that this objective was a secondary one. It was given less thorough treatment than the others and was included in part to provide convenient introductions to more central interview questions on fire prevention knowledge and attitudes.

Several surveys related to the present one have been conducted in the United States, although none of them meets the study objectives that have been outlined.

The two previously mentioned studies (Folkman 1965, 1973) were conducted in Butte County, California. The present study covers many of the same topic areas and has drawn heavily on the earlier work for construction of the interview form. Butte County is a predominantly rural area within a forest environment, and residents make local use of its wildland areas. This is a very different population from wildland visitors from metropolitan areas. The communication of fire prevention messages is highly complex, and must be modified to fit the wildland use, attitudes, knowledge, residential, and demographic characteristics of the audience. Results of these earlier studies are therefore not appropriate.

The Smokey Bear Study (Haug Associates 1968) was conducted in selected small and medium-sized cities in 1967. As its name implies, it primarily evaluated the Smokey Bear campaign. It did include questions to measure forest fire prevention attitudes, and some of these questions appear in the present study, but it did not include information on fire prevention knowledge nor on types of wildland use. Large metropolitan areas also were specifically excluded from its sample.

Another study of the Smokey Bear campaign was published after the field work for our study was completed (AHF Marketing Research 1976). It covered essentially the same questions as the earlier study of Smokey Bear, but the national probability sample used did include respondents from large metropolitan areas.

Other related studies are the North Pacific Border Study (Cheek and Field 1972) and the Piedmont Study (Payne and others 1973) undertaken for the National Park Service. Both included large metropolitan areas in their samples but were principally focused on the use of parks, especially visits to

National Parks and National Park Service areas. Neither included survey questions on fire prevention knowledge or attitudes. Their successful use of telephone interviews for studies of park use, however, was helpful in shaping the design of the proposed study.

METHODS

The study design and the interview schedules were developed in cooperation with the staff of the Survey Research Center, University of California, Berkeley. The sample was developed by William L. Nicholls II, and interviews were conducted by the Survey Research Center's staff of trained interviewers.

A random-digit-dialing telephone interview survey with a two-stage interviewing plan was adopted as the most cost-effective method of collecting the information specified by the study objectives.¹ Households were sampled by following the general procedures developed by Cooper (1964).

Within each metropolitan area a probability sample of telephone households was interviewed to identify those which did and did not contain wildland visitors and to obtain background information for comparative purposes. Nonvisitor households were also asked their reasons for not using wildland areas. Then, in visitor households, one wildland visitor was selected for a more detailed interview on the nature and extent of his or her wildland use, fire prevention knowledge and attitudes, and exposure to channels of fire prevention communications.

The majority of questions in the main schedule closely paralleled those of an earlier personal interview survey of forest fire prevention knowledge and attitudes (Folkman 1965) conducted in Butte County, California, a predominantly rural area. Question wordings were modified, however, to accommodate plans for telephone interviewing. Additional questions were based on items from the Smokey Bear Study (Haug Associates 1968) or were developed to take account of newly emerging topics, such as the

changing public image of forest rangers. Spanish versions of the interview schedules were prepared for Spanish-speaking respondents.

The study populations were defined as telephone households in the Los Angeles-Long Beach (LAMA) and San Francisco-Oakland (SFMA) standard metropolitan statistical areas of the 1970 U.S. Census. The LAMA consists of the County of Los Angeles. The SFMA includes Alameda, Contra Costa, Marin, San Francisco, and San Mateo Counties. Together, these two metropolitan areas contain more than half of the residents of the State. An estimated 92 to 94 percent of the residents of these areas were reachable by telephone.

Samples of approximately equal size were planned for the two metropolitan areas, since they represented different settings and anticipated use patterns of equal interest. Minimum sample sizes, established by funds available for field work, were set at 700 completed interviews per area, including both visitor and nonvisitor interviews. These minimums were exceeded in both areas (*table 1*).

The timing of the survey was the result of necessity rather than design. Original plans called for interviews in September-October 1975, when wildland experience of the preceding summer could be more easily recalled. Notification of U.S. Office of Management and Budget clearance (not affecting design or instruments) was not received, however, until February 1976. To complete the work by the contract termination date, interviews were held between March 24 and May 22.

The California winter of 1975-76 was the driest in the previous 50 years, and while interviewing was in progress the mass media devoted considerable attention to the prospects of a water shortage and increased forest fire hazards during the coming months. As a result of these unusual circumstances, public awareness and concern regarding forest fires, as reflected in the interviews, may be somewhat greater than would be expected during normal spring periods.

¹ Details of the methods are given in the report by William L. Nicholls II, *Sampling and field work methods of a telephone survey of urban users of California wildland areas*, available on request from the Wildfire Prevention Work Unit, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

Table 1—Field outcomes of sampled telephone numbers by area

Outcome	Los Angeles metropolitan area	San Francisco metropolitan area	Total
Sampled numbers	1,530	1,705	3,235
Percent nonworking	26.5	32.7	29.8
Percent working	73.5	69.3	70.3
Working numbers	1,124	1,148	2,272
Percent nonresidential (business, office)	21.7	20.8	21.3
Percent never answered	2.6	2.0	2.3
Percent residential	75.6	77.2	76.4
Residential numbers	850	886	1,736
Percent completed interview	86.8	86.4	86.6
Percent refused	10.5	11.1	10.8
Percent inaccessible (ill, out of town, etc.)	2.7	2.5	2.6
Estimated total completion rate ¹	84.9	85.3	85.2

¹The estimated total completion rate is the percent of completed interviews among residential numbers after adjustment for residential numbers among those never answered.

Table 2—Nonvisitors' reasons for not visiting California wildland, by metropolitan area, 1976

Reason	Los Angeles metropolitan area n=443	San Francisco metropolitan area n=363
	<i>Percent</i> ¹	<i>Percent</i> ¹
Prefer other things	56.0	54.5
Something makes it difficult	39.3	37.5
Confined by age or illness	11.7	18.2
Lack of transportation	8.6	7.7
Economic reasons	2.9	.6
Time constraints	16.0	11.3
Other constraining reasons	1.6	.8
Other nonconstraining reasons	2.3	1.9
Difficult and prefer other things	4.7	8.0
Confined by age or illness	.4	2.2
Lack of transportation	.7	.8
Economic reasons	.7	.6
Time constraints	2.9	3.9
Other constraining reasons		
Other nonconstraining reasons	.7	.6

¹ Percentages (in italic) that apply to specific reasons may add to more than the total for that general category, as some persons gave more than one reason.

RESULTS

Wildland Use and Wildland Users

The first objective was to explore the extent of wildland use by residents of metropolitan areas, the reasons for non-use, and the characteristics of users and non-users.

Occurrence of Wildland Visiting

Wildland use is affected by a variety of influences, such as physical access, competing attractions, and differing values and interests. For this reason, we expected to find considerable difference between the SFMA and the LAMA, and between both of the metropolitan areas and the rural areas previously studied. In general, we anticipated our survey to show SFMA residents to have better access to the wildlands than do LAMA residents. The results of this survey bore out this impression: 53 percent of the SFMA households reported that adult household members had visited a wildland area in California in the previous two years, as compared to 40 percent of the households in the LAMA.² The Butte County, Cali-

fornia, studies of more rural populations reported the contrasting figures of 76 percent (Folkman 1965) and 68 percent (Folkman 1973). (These figures are for visits during just the previous year, not the previous two years as in the current study.)

Reasons for Not Visiting Wildlands

The most frequent reason for not visiting was simply that the respondents—over half of them—preferred to do other things (*table 2*). Some stated that something such as time constraints, or physical incapacity due to age or illness, made it difficult to visit such areas. Economic reasons were seldom specifically mentioned, but in view of the socioeconomic characteristics of the respondents, economic circumstances can be assumed to influence wildland activity more than the reasons reported might indicate. Respondents in households headed by a female, or by someone who was older than the average, as well as those whose family income was lower than average, were more likely to state that their not visiting was due to some difficulty rather than merely to a preference for other types of activity (*table 3*). Education, years of residence in California, household size, and number of household members under 18 were not found to be significantly related to type of reason for not visiting wildlands.

Visitor and Nonvisitor Households

Differences in socioeconomic characteristics between visitor and nonvisitor households were quite marked, and were consistent for both areas studied

² Differences singled out for discussion throughout this paper (unless specifically indicated) are those deemed to be large enough to be of practical significance. They are also, of course, statistically significant ($p = 0.05$ or less) as determined by chi square or other tests appropriate to the data. Statistical significance must be interpreted carefully, however, where many independent tests are conducted on a single set of data.

Table 3—Relation of nonvisitors' average age, income, etc., to reason for not visiting wildlands.

Characteristics	Los Angeles metropolitan area			San Francisco metropolitan area		
	Something makes it difficult	Difficult and prefer other things	Prefer other things	Something makes it difficult	Difficult and prefer other things	Prefer other things
Age (years)	50.2	44.0	46.8	54.7	51.9	48.5
Income (dollars)	9,520	10,440	13,130	8,950	12,120	12,150
California resident (years)	5.2	4.5	5.3	5.2	5.2	5.4
Education (grades completed)	12.0	12.8	12.2	11.5	12.4	12.2
Household size (number)	2.6	2.6	3.0	2.6	2.9	2.9
Household members under 18 (number)	.8	.7	.9	.6	.8	.8
Female household head (percent reporting)	37.4	28.6	27.0	39.7	24.1	25.8

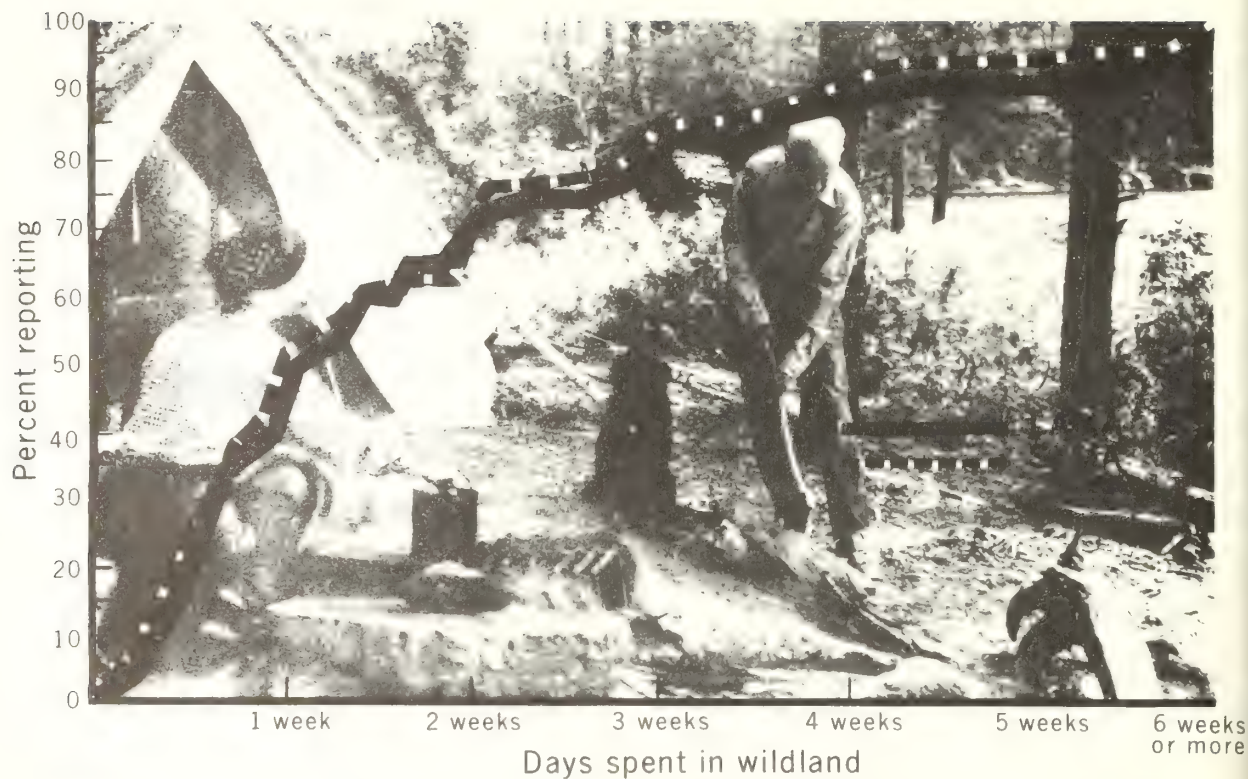


Figure 1—Most visitors spent between 7 and 8 days in California wildlands, as shown by this cumulative frequency curve.

(table 4). Differences in family income, age, amount of education, ethnic identification, occupation, and occupational status of household head were all related to whether or not a family member had visited the wildlands. The total family income in approximately half of the nonvisitor households was less than \$10,000. Only one-fourth of the visitor households had this small an income. Conversely, about a third of the visitor households had incomes over \$20,000, whereas only a sixth of nonvisitor households did.

Although nonvisitor households did not differ greatly from visitor households in average number of adult members (the difference was statistically significant only for SFMA), there were noticeable differences in detail. Nonvisitor households had a higher proportion of one, two, or seven and more household members. Similarly, although the majority of both visitor and nonvisitor households had two adults, a higher proportion of nonvisitor households had three or four adults. A higher proportion of nonvisitor households also had no members under 18, although many households did have three, four, or more non-adult members. The average number of children per household did not differ significantly.

Considerable information was gathered on the

characteristics of the heads of visitor and nonvisitor households (table 5). Both types of households were most frequently headed by males, although in the nonvisitor households, a considerably higher proportion were female. The heads were also more frequently older; the difference in the proportions of heads 65 or more years of age being especially noticeable. These differences were most marked in the SFMA.

On the average, heads of visitor households were more than one full school grade in advance of heads of nonvisitor households in schooling, and were more apt to have at least some college education. Those from nonvisitor households were more likely to have reached high school level, or less.

Except for American Indians, ethnic minority households were less likely to include wildland visitors than were the white or Anglo households.

Visitor and nonvisitor households were not markedly distinguished in type of occupation of the head. Some categories, however, did tend to be over-represented among visitor households: professional, technical and kindred workers; managers, officials, and proprietors; and sales workers. Service workers were over-represented among nonvisitor households.

The occupational status of household heads was

Table 4—Percent of surveyed wildland visitor or nonvisitor households, by metropolitan area, showing various socioeconomic characteristics, 1976

Characteristics	Los Angeles metropolitan area		San Francisco metropolitan area	
	Visitor (n=278)	Nonvisitor (n=367)	Visitor (n=383)	Nonvisitor (n=302)
Total family income:				
Under \$10,000	25.6	48.5	27.2	52.7
\$10,000–14,999	24.1	18.5	17.4	18.2
\$15,000–19,999	19.8	16.4	20.4	14.2
\$21,000–or more	30.5	16.6	35.0	14.9
Mean	\$14,990	\$11,575	\$15,348	\$10,935
Household size (members):	(n=294)	(n=442)	(n=401)	(n=360)
1	16.7	21.5	16.0	23.1
2	30.3	34.6	26.7	33.9
3	18.7	13.8	21.2	15.6
4	19.0	14.0	18.5	12.8
5	9.5	9.3	9.2	7.2
6	4.1	3.6	5.2	3.1
7 or more	1.5	3.2	3.2	4.5
Mean (members)	2.9	2.8	3.1	2.7
Household members under 18 years of age	(n=296)	(n=442)	(n=401)	(n=358)
None	56.7	62.9	55.4	62.5
1	17.1	12.0	19.0	15.4
2	16.0	12.9	15.2	12.3
3	6.5	7.9	6.5	5.3
4	1.7	2.0	1.7	2.5
Five or more	2.0	2.3	2.2	2.0
Mean (number)	.9	.8	.9	.8
Number of adult household members:	(n=293)	(n=441)	(n=401)	(n=357)
1	24.6	27.3	19.7	29.1
2	51.2	55.8	51.6	52.4
3	16.4	9.7	20.2	12.0
4	5.1	4.7	6.2	3.1
5	1.4	1.6	1.5	2.5
6	1.0		.2	.3
7 or more	.3	.5	.5	.6
Mean (number)	2.1	2.0	2.2	2.0

marked by the comparatively low percentage of non-visitor household heads who were working full time, and the high percentage who were in a retired or disabled status; nearly one-third were in the latter

category in SFMA.

Household heads who had resided in California but a short time, or who had lived there for more than 20 years, were less likely to be wildland visitors.

Table 5—Percent of heads of surveyed wildland visitor or nonvisitor households, by metropolitan area, showing various socioeconomic characteristics, 1976

Characteristic	Los Angeles metropolitan area		San Francisco metropolitan area	
	Visitor	Nonvisitor	Visitor	Nonvisitor
Sex:	(n=291)	(n=443)	(n=403)	(n=363)
Male	75.6	68.8	76.9	69.1
Female	24.4	31.2	23.1	30.9
Age (years):	(n=295)	(n=422)	(n=402)	(n=350)
Under 25	8.5	5.7	11.9	3.4
25 to 34	30.5	19.0	34.1	13.1
35 to 49	32.5	29.4	29.8	30.4
50 to 64	22.4	26.0	17.7	29.4
65+	6.1	19.9	6.5	23.7
Mean (years)	37.3	47.9	36.6	51.1
Median	34.1	47.1	32.5	50.3
Range	17-74	18-91	17-88	19-89
Highest grade of school completed:	(n=293)	(n=430)	(n=400)	(n=343)
None	.3	1.4	—	2.3
Grades 1-6	.3	5.8	1.0	4.4
Grades 7-8	1.7	4.7	2.0	6.4
Grades 9-11	6.1	12.3	4.0	12.5
Grade 12	27.7	31.7	23.3	34.1
Some college	30.1	18.8	31.0	17.8
College graduate	17.8	16.5	18.0	14.6
Graduate work	16.0	8.8	20.7	7.9
Mean	13.5	12.2	13.8	12.0
Ethnic identification:	(n=288)	(n=437)	(n=395)	(n=353)
White	82.7	64.0	83.3	67.5
Black	6.9	15.6	4.1	13.6
Mexican-American	5.2	12.8	3.3	4.5
Oriental	.7	3.7	4.3	7.9
American Indian	1.4	.5	1.5	—
Other	3.1	3.4	3.5	6.5
Resident in California (years):	(n=295)	(n=442)	(n=402)	(n=360)
Less than one	.7	3.2	1.2	3.6
1 to 2	1.7	2.7	4.7	.8
3 to 5	4.7	5.9	6.7	4.4
6 to 10	9.8	9.5	11.9	9.2

Characteristic	Los Angeles metropolitan area		San Francisco metropolitan area	
	Visitor	Nonvisitor	Visitor	Nonvisitor
Occupational status:	(n=293)	(n=443)	(n=401)	(n=360)
Working full-time	79.2	63.2	75.4	55.7
Working part-time	5.8	7.4	8.5	4.2
Looking for work or on lay-off	4.4	4.5	4.2	4.7
Retired or disabled	4.8	19.5	7.5	30.6
Attending school	2.7	.9	3.2	1.7
Keeping house	2.4	3.4	1.0	2.5
Other	.7	1.1	.2	.6
Occupation or former occupation:	(n=273)	(n=401)	(n=383)	(n=322)
Professionals, technicians, etc.	28.6	21.0	28.5	18.9
Proprietors, managers and officials	18.3	15.8	17.7	12.7
Sales workers	8.4	5.7	9.2	6.8
Craftsmen, foremen and related workers	11.4	12.7	11.5	14.9
Clerical and related workers	12.8	14.2	13.8	10.9
Service workers	4.8	11.0	8.1	13.4
Operatives, and related workers	11.0	10.7	6.3	13.4
Laborers	4.0	5.7	4.7	5.9
Private household workers	.7	2.5	.3	.9
Farmers, farm managers	—	.2	—	—
Armed Forces	—	—	—	1.9
Other	—	.5	—	.3

Wildland Users and Fire Risk

The second study objective was to describe and analyze the activities, knowledge, and attitudes of urban visitors of wildland areas which may contribute to their fire risk. Again, a "visitor" is defined as an adult who has made one or more visits to forest and wild grass or brush land areas in California within the past 24 months.

Extent and Type of Wildland Activities

Although the interviewing was conducted relatively early in the year for outdoor recreation (March 24 to May 22, 1976), 60 percent of the visitors (both SFMA and LAMA) reported having made at least one visit to California wildlands during the previous 6 months.

Approximately half (52 percent of the LAMA visitors and 46 percent of the SFMA visitors) reported that their most recent visit included a drive of more than 2 hours from their home. Only 6 percent of the LAMA and 2 percent of the SFMA visitors said they had never visited an area at that distance from home.

The number of days, or parts of days, spent in California wildlands during the previous 12 months was very similar for both metropolitan areas (fig. 1). The median number was between 7 and 8 days. Some respondents spent considerably more time than this in the wildlands, however, so that the resultant mean was approximately double that of the median—2 weeks instead of 1.

Walking and driving through the wildlands and picnicking were the forms of activity most popular with forest visitors (table 6). Again the results are quite similar for visitors from both metropolitan areas. About half the visitors reported that they had remained overnight in the wildland; about a third said that this had been in a developed campground. The proportion reporting that they had spent at least one night in a tent or under the stars in a campsite they had made themselves was half as large as that reporting using a developed campsite.

While it is true that developed campgrounds have been made relatively fire-safe, many of the activities reported take place outside such places and bring the participants into intimate contact with the fire-fragile environment of the California forest or wild grass or brush land. The use of fire is implicit in several of these wildland activities (15 percent of the visitors from LAMA and 22 percent from SFMA said that they had obtained fire permits, suggesting that they had intended to build fires outside of developed

Table 6—Activities reported by visitors to California Wildlands, 1976

Activities	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)
	Percent	
Driving through area (off main highway)	61.7	65.3
Picnicking	50.8	59.8
Building camp or warming fire	27.5	31.0
Walking (at least one-half mile)	73.9	74.2
Hiking (off main trails, one mile or more)	40.3	40.3
Fishing	26.4	29.0
Hunting	4.7	6.9
Staying over night:		
in developed campground	53.9	50.9
in undeveloped site	36.3	30.8
	15.6	15.9
Obtaining campfire permit	15.3	21.6

campgrounds). Although smokers are urged to avoid smoking in wildland areas and if they must smoke, to exercise precautions, we must expect that there are frequent deliberate or unconscious lapses from recommended practice. Over one-third of the respondents said they were smokers.

Knowledge of Forest Fire Prevention

Although a person's actual behavior may be quite at variance with his knowledge of appropriate behavior, in the absence of measures of such behavior we must assume that whether or not the forest visitor is knowledgeable about fire danger has a bearing on the degree of fire risk the visitor represents. A series of questions probed the understanding of forest visitors from metropolitan areas of conditions making for fire hazards, the human role in forest fire starts, fire safety regulations and practices, and related forest fire matters.

When queried concerning the kinds of weather that most increase the danger of forest fires, three-fifths of the visitors mentioned high temperature and low humidity (table 7, item 14).³ Those from LAMA were more aware of the role of wind than were visitors from the SFMA: the effects of the notorious Santa Anas of Southern California have been quite

³ Tables 7, 8, and 9 will be found on pages 18-22.

widely publicized. Drying winds also contribute to hazardous fire conditions in other parts of the state, but have not been given as much public attention.

One in five LAMA residents thought that green trees and shrubs in California will catch fire only during the hottest summer days (*table 7*, item 20a).³ The SFMA respondents revealed no higher proportion of correct knowledge, but they were more willing to admit they did not know. The respondents revealed even less knowledge about the timing of the fire season by their agreement with the statement that the danger of forest fires in California rises in August and then tapers off (*table 7*, item 20q). Over half called this true, apparently unaware that there is a continual build-up until the advent of the rainy season, and some of the worst fire weather often occurs in September or October. Less than a third gave the correct answer. The remainder admitted they did not know.

Most respondents were aware that human carelessness is responsible for a majority of forest fires (*table 7*, item 12). Few took the opportunity to give examples, but carelessness with smoking materials was most frequently mentioned by those who did specify. There was some overestimation of the proportion of forest fires in California that are started by human carelessness, but for fire prevention, this is a helpful tendency (*table 7*, item 13).

Three of the knowledge items probed respondents' understanding of fire safety regulations (*table 7*, items 20h, 20i, 20o). Seven out of 10 were aware that a campfire permit does not give you permission to build an open campfire anywhere in a forest away from residential areas, but only about a third of them knew that where campfire permits are required, they are also needed for gasoline or propane campstoves.

The use of "closures" to control fire risk in forest areas during periods of high hazard is more common in the southern part of the State, but respondents from both SFMA and LAMA proved equally familiar with the term. Seven-eighths of those interviewed in both areas correctly answered this item.

Five items tested knowledge of common fire safety practices (*table 7*, items 20b, 20d, 20f, 20k, 20n). Again the responses from the two metropolitan areas were very similar. Most respondents were aware that one should avoid driving a vehicle through dry grass or brush and that it is very dangerous to carry extra gasoline in a plastic container; however, two-thirds still had the misconception that the safest way to put out a campfire is to cover it with loose dirt, ignoring the danger of the fire later escaping, as fuel settling or wind uncovers live embers. Three-

fourths were familiar with the forest practice of breaking a match in two before discarding it, but a lesser proportion were aware that a lighter is safer than book-type matches.

Seven items of the knowledge questionnaire concerned with related forest fire knowledge revealed widely differing levels of knowledge for different items, although the responses from the two metropolitan areas were very similar (*table 7*, items 20c, 20e, 20g, 20j, 20l, 20m, 20p). Many people shared the common misconception that forest fires are often caused by spontaneous combustion. They were fairly well aware, however, that a fire may smolder inconspicuously for some time before it erupts into flame. They recognized that most people who start a forest fire through carelessness remain unaware of what they have done. The majority did not know that a campfire can start a forest fire by burning through roots underground, and three-fourths were either misinformed or did not know the extent of liability for a carelessly started forest fire.

Attitudes Toward Forest Fire Prevention

The variety of attitudes presumed to be related to fire risk were explored through items dealing with awareness of fire threat, impression of the seriousness of forest fires, attitudes toward wildland rules and regulations, attitudes toward persons displaying high fire risk behavior, and attitudes toward governmental agencies responsible for wildland management.

Large-scale catastrophic brush fires are more common in southern California. Their dramatic coverage by the communications media intensifies their immediacy for residents of this area. Consequently, respondents from the LAMA might be expected to be more apt to say they follow news accounts of forest fires very closely than would those from the SFMA (*table 8*, item 15b).³ Differences between the groups on items related to reaction to environmental fire hazards or incautious behavior of others when they are in a wildland area (*table 8*, item 15a, 15c, 15f) are not so marked, however.

To assess the seriousness with which the respondents viewed the forest fire problem, they were asked to state which was the most serious property-damaging phenomenon in the state—floods, smog and air pollution, forest fires, landslides, or earthquakes (*table 8*, item 8a, 8b). The question was asked early in the interview, before there was any indication that forest fires were the focus of the survey. Forest fire was a decided first choice. It was selected twice as frequently as the runner up—smog.

³ Tables 7, 8, and 9 will be found on pages 18-22.

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In recent years, considerable public concern has centered on logging practices. In some circles "clear-cutting" has become an opprobrious epithet. This is, no doubt, reflected in responses to the statement that, on the average, fires probably do less damage to the forests than logging (*table 8*, item 9c). Those from the SFMA were quite evenly divided between agreement and disagreement; more LAMA respondents disagreed, although over a third agreed.

Nearly three out of four disagreed with the statement that grass and brush fires are mostly a nuisance and do little real harm (*table 8*, item 9d). The response was similar, but a little stronger, to the statement that harm from forest fires is often exaggerated (*table 8*, item 9e). SFMA respondents were slightly more inclined to agree with both of these items than were those from the LAMA.

Other items designed to measure subjective impressions of the harm done by forest fires were a series on the necessity of fighting forest fires (*table 8*, items 9a, 9b, 9f, 9g). Current fire management philosophy recognizes that fire has had strong influence on the development of forest and range ecosystems. Given certain land management objectives and under specific conditions, fire may be a useful and beneficial ally. Fire prevention specialists recognize this fact, but fear that the general public may not grasp the nuances of this philosophy and may assume that it condones indiscriminate starting of fires. The results of this survey are open to interpretation. Over half the respondents agreed that an occasional forest fire is part of nature's plan for renewing the land, but nearly three-fourths did not agree that forest fires that start from natural causes should be allowed to burn if they don't threaten life or private property. What is essentially the reciprocal of this statement—"It's important for government agencies to stop each forest fire as soon as they can, no matter where it occurs"—drew an even larger proportion of responses in agreement, as did the statement that "tax money spent fighting forest fires is always well spent."

About two in five persons thought the number of major forest fires in California had gone up over the last 5 years (*table 8*, item 10). A similar proportion felt that it had remained about the same. Only about one in eight felt that the number had decreased.

An inquiring reporter for a San Francisco newspaper a few years ago asked people what they liked about being in the wilds. One response was that they liked feeling free from all laws and regulations. Wildland managers, of course, do attempt to enforce regulations to prevent abuse of the resource, as well as injustice to other users. But, a sense of release from

the pervasive restrictions of everyday life is, no doubt, part of the appeal of wildland recreation. Respondents were therefore given a series of statements related to such rules and regulations (*table 8*, items 6a-f, 15e).³ The general consensus was that such rules and regulations are necessary, generally fair and reasonable, and no stricter than they need to be. Respondents were especially conscious of the need for strict smoking and campfire rules. However, there was a feeling, expressed by more than one in three, that fire regulations are pretty much just a matter of common sense—experienced campers would not need to give special thought to them.

Most people did not seem to feel that forest rangers' enforcement of rules restricted their freedom too much. In fact, approximately two-thirds of the respondents felt it would be desirable to have more rangers engaged in enforcement of forest regulations.

Wildland visitors appear to feel some responsibility for the protection of the forest. The vast majority indicated that they would take some personal action if they observed someone using fire carelessly (*table 8*, item 17). Four out of five said they would caution the individual. Most of the remainder said they would report such a person. Only a few admitted that they would let others take care of the situation.

Being made to pay a fine was the punishment that most respondents (two out of three) felt would be appropriate punishment for accidentally starting a forest fire (*table 8*, item 18). About 1 out of 6 felt that a warning was sufficient, while 1 in 10 thought such a person should be jailed. A few suggested that the guilty party should be required to help with reforestation, or make similar restitution.

In this era of general disenchantment with governmental activities, forestry agencies appear to have retained a fairly high level of credibility among forest visitors (*table 8*, item 7a, 7b). Seven out of 10 wildland visitors felt that the agencies were doing a good or very good job in taking care of California's forest and wildlands. They were slightly more impressed (8 in 10) with the job the agencies were doing in making the wildland experience enjoyable for visitors. It was reported earlier that most respondents did not feel that agencies exaggerate the harm done by forest fires (*table 8*, item 9e). However, about one-fourth did feel that the agencies might exaggerate *fire danger* in order to encourage visitors to abide by the fire regulations (*table 8*, item 15d).

³ Tables 7, 8, and 9 will be found on pages 18-22.

Attitude and Knowledge Scores

Most of the statements probing knowledge about fire prevention and fire behavior and related attitudes had been used in our previous studies. Changes were made on the basis of experience, and the format was modified for telephone interviewing. The knowledge items were changed to a true-false form rather than multiple choice, and the attitude items to a simple agree or disagree response, without an attempt to measure degree.

Factor and reliability analysis was used to produce indices for further analysis. As a result of this analysis, some attitude items were dropped and the remainder combined in summary measures of three dimensions of fire-related attitude: (1) awareness of forest fire threat (*table 8*, items 15c, 15d, 15e, 15f);³ (2) subjective impressions of the role of fire in wildlands (items 9a-9g); and (3) attitudes toward wildland rules and regulations (items 6a-6d, 6f). For convenience, these groups are referred to in the discussion as Threat, Let Burn, and Regulations.

Because probability theory cannot be applied to this type of analysis, a significance level for applicability to the sampled population cannot be assigned. However, these methods are invaluable in "making sense" of complex data.

Aggregate attitude scores for these three dimensions are based on giving positive responses a weight of 3, negative responses a weight of 1, and "no opinion" an intermediate weight of 2 on each item. Scores are reported on the basis of percent of a theoretical possible score. Responses were considered positive if they reflected agreement with prevalent values of fire prevention. For the "Let Burn" dimension, responses in harmony with a policy of exclusion of fire from wildlands were recorded as positive, although fire prevention policy currently recognizes the role of fire in the development of certain ecological systems.

The knowledge items tapped such a complex variety of information that it was not possible to extract any scaleable set of factors. It was decided to use a simple aggregate score representing the percent of possible correct responses (referred to as "Knowledge" in the following discourse). Scoring on the basis of number correct minus number wrong, to adjust for possible guessing, proved to be very highly correlated with scores based on percent correct so this simpler method was used.

A measure of wildland activity ("Activity") based

on number of days, or part of days, spent in forests and other wildlands in California in the previous 12 months expressed as percent of largest number of days reported, was found to provide as effective a measure as one based on a combination of complexly weighted types and frequencies of different wildland activities.

An examination of the correlation matrix (*table 9*)³ shows that these various measures bear weak relationships to each other. To the extent that the attitude scales tap different dimensions, such lack of correlation is acceptable, but to find that frequent visitors to wildlands are not more knowledgeable than those who seldom go is quite disconcerting when one considers the implications for fire risk.

Mean scores on the various measures obtained by respondents in the LAMA were very similar to those obtained by the respondents in the SFMA. Although the mean Activity scores appear to show a higher level of wildland visiting by SFMA respondents, this difference is not statistically significant. Although changes in format and procedure prevent precise, direct comparisons, the knowledge scores of 58 percent (LAMA) and 59 percent (SFMA) correct, obtained by the two metropolitan samples, indicate that these wildland visitors from urban areas are equally as knowledgeable about fire prevention as those from more rural environments (Folkman 1965, 1973). In these previous studies the scores were 58 and 57 percent, respectively. High average scores on the two attitude measures, Regulations and Threat, suggest a very high positive feeling about the aspects of the fire prevention situation these measures tap. This confirms the findings of a recent study of the national Smokey Bear program, which found an overwhelming majority endorsing fire prevention efforts (AHF Marketing Research 1976). Lower average scores on the Let Burn scale no doubt reflect the difficulty the general public has in reconciling a management philosophy that recognizes the desirability of accepting fires of natural origin while enforcing strict regulation of man-caused fires.

Relation of Attitude and Knowledge Measures to Other Variables

We expected that attitude and knowledge scores would vary considerably with the frequency and type of wildland experience and with demographic and other background characteristics of the visitors. However, differences were not found as frequently as

³ Tables 7, 8, and 9 will be found on pages 18-22.

³ Tables 7, 8, and 9 will be found on pages 18-22.

anticipated and the magnitude of the differences was seldom very great, often failing to reach statistical significance for one or the other metropolitan area sample. In the following discussion, significant differences are noted by area—(LAMA) or (SFMA). Unless so noted, however, data from one area were consistent with those of the other.

Wildland Activity—As expected, participation in various types of wildland activity (driving through, picnicking, hiking, camping, and so on) is rather closely and positively correlated with number of days spent in California wildlands (Activity). In the main, however, fire prevention attitudes and knowledge do not vary with such participation. Where statistically significant differences did appear, attitude scores tended to be lower for those who had participated than for those who had not. Most of those differences were associated with Threat—respondents who reported driving in wildlands, fishing, camping overnight outside of an established campground (LAMA), and respondents who reported having built a campfire or warming fire, or gone hunting (SFMA), had significantly lower scores in the Threat dimension. Lower scores on the attitude measure Regulations (LAMA) were also reported by respondents who had gone hunting or camped overnight outside an established campground. Respondents who had done some hiking off main trails and those who had obtained campfire permits tended to have higher fire prevention knowledge scores than did others (SFMA). However, those who reported camping overnight outside an established campground tended to have lower Knowledge scores (SFMA). No wildland activity was related to the Let Burn attitude measure.

Residence—Residents in suburban SFMA had statistically significant higher knowledge scores than those from other parts of the area. No other relation to residence was evident for any of the measures of attitude, knowledge, and wildland activity in either metropolitan area.

Demographic and Socioeconomic Characteristics—Age was the characteristic most consistently related to variations in fire prevention attitudes and knowledge. Mean scores on Regulations and Threat were lowest (most negative) among persons under 25 years of age and highest among those 65 or over. Knowledge scores followed a similar pattern, except that the progression was not consistent at the upper age levels. Activity levels proved highest for persons under 25, and next highest for those 65 and over (LAMA).

The attitude scores of females tended to be more positive than those of males, and the reverse for knowledge scores. Scores on the Regulations dimen-

sion did not differ significantly by sex (SFMA), nor did scores on Let Burn (LAMA).

Marital status accounted for some variation in attitude and knowledge, particularly among those from the SFMA. Married persons had higher average scores on the Regulations, Threat, and Knowledge measures than those who had never been married. Those widowed, divorced, or separated tended to have more intermediate scores, and the never married had the lowest scores.

Persons with family incomes under \$10,000, or \$20,000 or more, had higher scores, on the average, on the Let Burn dimension; those with incomes between \$10,000 and \$15,000 had higher than average scores on the Threat dimension. Those with family incomes of \$20,000 or more had higher average scores on the Regulation and Threat dimensions (SFMA).

In addition to the above, respondents differed significantly in the following ways: White collar workers had higher average scores on the Regulations and Threat dimensions than did blue collar workers (SFMA). Persons who were retired, students, or housekeepers had higher Threat scores on average than did those who were in the labor force (SFMA). College graduates had higher average Let Burn and Knowledge scores than did those with lesser education (SFMA). The Knowledge scores of suburban residents averaged higher than those of the central cities (SFMA).

Exposure to Information Sources

Fire prevention workers desire to bring their message to the attention of wildland visitors as effectively and efficiently as possible. Three main types of communication channels are used. The mass media channel is heavily relied on to reach the widely dispersed visitor population in their home environment; it is diffuse and broad-focused, and largely unable to distinguish between wildland visitors and nonvisitors. A more specific channel is contact through various voluntary organizations whose membership might be expected to include many wildland visitors. The most specific channel is direct contact with the target group while they are in the wildland. There are difficulties in reaching people effectively when they are scattered over a large expanse of wildland, but there is also assurance that those reached are the ones who should be influenced.

Although choosing appropriate and effective channels for dissemination of fire prevention educational materials is important in planning an action

program, this concern was not explored in depth. Interview items were included mainly to provide convenient introductions to more central questions on fire prevention knowledge and attitudes. These data do have some implications for the subject, however.

Type of Channel

Mass Media—The question of whether or not the respondents recalled seeing or hearing any message or information about forest fire prevention through the various mass media, during the previous month or so, was answered affirmatively by slightly more than half of the respondents (57 percent in LAMA and 55 percent in SFMA). The sources mentioned were similar for the two areas.

		LAMA (n=163)	SFMA (n=214)
Source:		<i>Percent Reporting</i>	
☐	Television	44	45
☐	Billboards	35	30
☐	Magazines	10	7
☐	Newspapers	3	6
☐	Radio	2	4
☐	Pamphlets	2	3
☐	Displays	1	2
☐	Other	2	3

It is surprising that radio was mentioned so infrequently, because fire prevention announcements are given nearly as often on radio as on television.

Voluntary Organizations—Membership in voluntary conservation organizations was not found to be widespread; only slightly more than one in ten (10 percent for LAMA and 14 percent for SFMA) said they did belong. Membership was distributed among a variety of organizations. The Sierra Club, with 5 percent of the SFMA and 2 percent of the LAMA respondents, had the highest representation. The National Audubon Society, with 2 percent of SFMA respondents, was the only other single organization with more than a fraction of a percentage of representation. Local or minor organizations with primary or subsidiary interest in conservation, together, accounted for 5 percent of the response in both metropolitan areas.

Direct Contact—Direct personal contact, generally recognized as most effective in influencing behavior change, was implied when respondents were asked if they had visited any National or State Park or Forest in the last year where they were handed a list of rules and regulations when they went in. Approximately half (46 percent, LAMA; 53 percent, SFMA) said they had; of the remainder, 30 percent (LAMA) and 26 percent (SFMA) said that they had seen such a list

posted on a sign in the area. Some indication of the relative efficacy of the two methods was gained through a question as to whether the list was read through, or either just glanced at or not even looked at. Of visitors who were directly handed the list of regulations, approximately three out of five (57 percent, LAMA; 61 percent, SFMA) said they read them through. Of those who merely saw the rules posted, the proportions who reportedly read them were considerably less (44 percent in LAMA, and 33 percent in SFMA).

Littering regulations were most frequently remembered, campfire regulations only slightly less frequently. Respondents from the LAMA were more likely to recall the smoking regulations, while the SFMA respondents tended to remember rules concerning pets.

Relation to Other Factors

Fire Risk—The relation between exposure to communication channels, and fire risk, as measured by fire prevention attitudes and knowledge scores and wildland visit frequency, was found to be fairly weak. Those who recalled being handed a list of regulations did tend to be more frequent wildland visitors and to have higher Knowledge scores (SFMA). Those whose experience was limited to regulations posted on signboards had lower Regulations scores on average (SFMA). Those who claimed to have read the list of regulations tended to be more frequent visitors and to have higher Regulations and Knowledge scores.

Frequent visitors to wildlands were more likely to recall seeing or hearing fire prevention messages by way of the mass media (LAMA). Respondents who were members of conservation organizations tended to have higher Knowledge scores. They also tended to be more favorable to the Let Burn philosophy (SFMA) and to be more frequent visitors to wildlands (LAMA).

Residence—The attempt to relate communication to place of residence proved particularly unfruitful. Visitors from suburbs (SFMA) more frequently reported having a list of regulations handed to them, but this was the only significant difference noted.

Demographic or Socioeconomic Characteristics—Being handed a list of regulations or merely seeing them posted was not related to other variables except that visitors under 35 years of age were more likely to report the less personal contact (LAMA).

Persons who recalled having seen or heard a mass media-disseminated fire prevention message also tended to be younger than average (LAMA), have a high school education or less (LAMA), to have a family income of between \$10,000 and \$20,000

(LAMA), and to have a full-time occupation (SFMA). Those with a college education tended to mention magazines as the source of the message, while those with less education most frequently mentioned television (SFMA).

Members of conservation organizations are not apt to be typical of the general population. The study showed that they tended to be older (35 years of age, or older) than non-members (SFMA), college graduates (SFMA), and have a family income of \$20,000

or more (SFMA). This corresponds very closely with the findings of a recent study of Audubon Society members. They found the average member to be an executive, earning \$36,000 annually (26 percent in top and middle management positions and 40 percent engaged in professional or technical occupations). The median age was 44 years and the membership was composed of 58 percent males and 43 percent females, 85 percent had attended college and 43 percent had attended graduate school (Line 1977).

DISCUSSION

Human motivation is exceedingly complex. The reasons people gave for not visiting wildland areas, however honest, probably only partially reflect the influences on their choices. Aside from irreversible physical infirmity due to aging or illness, the types of reasons for not making wildland visits and some of the factors influencing these reasons are subject to modification, as social models, economic circumstances, stages of family life cycle, or other influences on the individual, change. If we can anticipate a continuing emphasis on wildland-based recreational activity in our society, we may expect a larger and larger proportion of urban residents participating. A general economic decline, on the other hand, would possibly force a larger share of current visitors to reluctantly join the nonvisitor ranks. Projections of the future age structure of our population suggest increased proportions in the older age brackets and corresponding reductions of the more youthful ones. To the extent that wildland activity is youth oriented, a future decrease in wildland use is suggested. However, if the projection implies a larger group of retirees who have relatively few economic, familial, or time restraints, we could expect a continued increase in the types of use favored by retirees. Effective fire prevention program planning will require a dynamic format adjusting to changing types of people making differing demands on the natural resource base and resulting in differing levels of fire risk.

When we consider only the wildland visitor portion of our sample, the two metropolitan areas studied are very similar in most respects. Although both metropolitan areas have wildlands conveniently nearby, much of the wildland use by residents takes place 2 or more hours driving time away from their homes and is of a week or more in duration.

While much use is made of developed camp-

grounds, which are relatively fire safe, many of the activities reported take place under more dispersed circumstances where the fire hazard is considerable. In addition, fire use in one or more forms is a frequent element of such activities.

A recent national survey of the Smokey Bear program (AHF Marketing Research 1976) revealed that practically all people in the United States held very favorable attitudes about forest fire prevention. In this study, we likewise found that negative attitudes could not be a significant factor in the forest fire problem. However, the level of knowledge reported revealed some areas of weakness in previous fire prevention educational efforts.

Differences do exist among wildland visitors in scores on various measures of attitude, knowledge, and activity. To the extent that these measures are valid, we may define relative fire risk, but when we attempt to associate different levels of risk with demographic and socioeconomic circumstances, we find general tendencies rather than sharp distinctions. The lower attitude levels shown by respondents who had higher levels of participation may be explainable as familiarity breeding—if not contempt—indifference. The reality testing provided by exposure might be expected to reduce an overly idealized concept of wildland. But this does not explain lower levels of knowledge.

Although our efforts have not revealed a mark of Cain that will readily distinguish the high fire risk forest visitor from others, we can point out the characteristics of those who, on the basis of our criteria, do appear to represent higher than average risk. The data are by no means conclusive, but they suggest that such high risk persons are most likely to be found among the young, single males from low or lower middle socioeconomic levels.

To a somewhat lesser extent, the older, retired

person who, although his attitude tends to be positive, tends to have a high activity level and low knowledge score, also represents a higher than average risk. These findings are very similar to those from our study of a more rural population (Folkman 1973).

The limited data gathered on communication channels do permit some observations. Personal contacts, as when visitors are handed fire prevention leaflets or other material, appear to have the greatest impact, and the frequency of such contact was related to Knowledge scores. It is apparent, however, that the educational effect of these contacts could be improved with a little more attention to how the contact is made and where the emphasis is placed. A visitor who is anxious about how his dog will be accepted in a campground is probably more likely to become aware of regulations about leashing (whether he observes them or not) than about campfires. The ranger who through personal contact is acquainting him with the regulations might help him rearrange his priorities.

The way the questions were asked does not permit a direct comparison of the effectiveness of such personal contacts with the more diffuse contact provided by the mass media. About half of the visitors recalled having been exposed to a mass-media-disseminated prevention message, with television and billboards the most frequently mentioned sources. Radio produced a surprisingly low rate of response.

Contacts through voluntary conservation organizations represent effective channels for reaching special types of frequent wildland visitors, but they, in total, represent a small fraction of all visitors.

From this study, and from other sources (AHF

Marketing Research 1976, Haug Associates 1968), it is apparent that people in all walks of life are aware of the forest fire problem and that they do favor fire prevention efforts. Therefore, the major future thrust, aside from some minor attention to maintenance of this awareness, should be in other directions. There are, for example, serious gaps in knowledge related to fire prevention—as shown by different types of forest users. Our problems would not be solved, however, simply by switching from attempts to change attitudes to attempts to present facts. It is apparent that adding high levels of knowledge to strong positive attitudes in itself would not be enough. The aim is behavior change. The merely rational view that people are capable of altering their attitudes, habits, and other patterns drastically once they are told the facts, usually leads to ineffective communication. People are not interested in *the facts*, nor do they know what to do with them, unless we, as communicators, not only tell them what to do, but show them how to do it in an explicit, interesting, dramatic, and, most important, persuasive manner.

Persuasion, however, has its own limitations in inducing behavioral change. Positive reinforcement, or feedback, immediately following desired behavior and the obverse, following lapses in desired behavior, have been proven to be more effective. Unfortunately, fire-related behavior occurs under conditions that make application of immediate feedback exceedingly difficult. Only innovative and creative departures from traditional fire prevention practice will surmount this problem.

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TABLES

Table 7—Distribution of responses of visitors to California wildlands to questionnaire items relating to forest fire prevention knowledge, by metropolitan area, 1976

Item ¹	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)	Item ¹	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)
	<i>Percent</i>				
What one thing do you suppose causes most forest fires? (12)			Many forest fires start just from the heat of the sun, whether people are there or not. (20c)		
Carelessness with cigarettes or matches or smoking	14.6	19.6	True	45.7	
Carelessness with campfires	4.1	7.2	False	37.6	
Carelessness, other, or unspecified	67.7	60.4	Don't know	15.3	
People who set fires deliberately	4.8	.7	No answer	1.4	
Acts of nature, like lightning, etc.	4.8	9.9	When lighting cigarettes in a forest, it is safer to use book type matches than a cigarette lighter. (20d)		
Other	3.7	2.2	True	10.5	
Don't know or no answer	.3		False	68.4	
About what proportion of forest in California would you guess are started by human carelessness (13)			Don't know	19.7	
Almost all	31.5	26.7	No answer	1.4	
Two-thirds	43.8	40.0	If a discarded cigarette is going to start a forest or grassfire, it will usually be obvious in a few minutes. (20e)		
Half	14.9	20.6	True	15.6	
One-third	5.1	8.7	False	76.3	
Less than that	2.7	2.0	Don't know	6.4	
Have no idea	1.7	1.5	No answer	1.7	
No answer	.3	.5	The surest way to put out a campfire is to cover it with loose dirt. (20f)		
Do you happen to know what kinds of weather most increase the danger of a forest fire? (14) ²			True	62.6	
High temperature, hot days	60.7	63.0	False	31.9	
Low humidity, dry air, little moisture in the air	62.4	59.8	Don't know	4.1	
Lack of rain, not raining, hasn't rained for a long time, drought	31.2	30.0	No answer	1.4	
Windy day, winds for several days	48.8	40.0	An open campfire can start a forest fire by burning through roots under the ground. (20g)		
Lightning or thunder storm	14.2	16.4	True	35.6	
Other	.3	.5	False	23.7	
Don't know or no answer	1.0	.7	Don't know	39.3	
In California, green trees and shrubs will catch fire only during the hottest summer days. (20a)			No answer	1.4	
True	19.0	16.4	Where campfire permits are required, permits also are needed for gasoline or propane campstoves. (20h)		
False	72.1	68.2	True	36.6	
Don't know	7.5	14.4	False	16.9	
No answer	1.4	1.0	Don't know	45.1	
If you use stick type matches in a forest you should always break them in half after putting them out. (20b)			No answer	1.4	
True	75.3	74.9	A campfire permit gives you permission to build an open campfire anywhere in the forest away from residential areas. (20i)		
False	12.2	12.2	True	6.8	
Don't know	10.8	11.9	False	70.4	
No answer	1.7	1.8	Don't know	21.4	
			No answer	1.4	

Table 7—Distribution of responses of visitors to California wildlands to questionnaire items relating to forest fire prevention knowledge, metropolitan area, 1976—Continued

Item ¹	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)	Item ¹	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)
People who start a forest fire through carelessness are unaware of what they've done. (20j)			Even a well-maintained car or motorcycle can start a fire if driven off the road through dry grass or brush land. (20n)		
<i>True</i>	81.7	89.6	<i>True</i>	85.4	81.8
False	10.5	6.2	False	5.1	5.0
Don't know	6.4	3.2	Don't know	8.1	11.7
No answer	1.4	1.0	No answer	1.4	1.5
It is dangerous to carry extra gasoline for a car, campstove, or outboard in a plastic container. (20k)			A sign in a National Forest that reads "Closed Area" means that you may not go into that area at all. (20o)		
<i>True</i>	82.0	85.2	<i>True</i>	87.5	87.6
False	7.4	6.9	False	4.7	3.0
Don't know	9.2	6.9	Don't know	6.4	7.9
No answer	1.4	1.0	No answer	1.4	1.5
Fire in the rotten vegetation on the forest floor smolders slowly with little visible smoke. (20l)			A person could be sued for his life savings if it was proved that he started a forest fire even through carelessness. (20p)		
<i>True</i>	65.0	66.0	<i>True</i>	27.5	23.6
False	11.9	9.9	False	18.6	17.4
Don't know	21.7	22.9	Don't know	52.5	57.5
No answer	1.4	1.2	No answer	1.4	1.5
Smoldering vegetation on the forest floor often produces enough heat to start a fire by itself. (20m)			The danger of forest fires in California reaches its peak in August and then tapers off. (20q)		
<i>True</i>	43.0	38.4	<i>True</i>	51.5	56.9
False	22.7	22.6	False	30.8	27.5
Don't know	32.9	37.5	Don't know	16.3	14.4
No answer	1.4	1.5	No answer	1.4	1.2

¹Numbers in parentheses following items are those used in questionnaire. Italic indicates correct response.

²Multiple response possible; percentages add to more than 100.

Table 8—Distribution of responses of visitors to California wildlands to questionnaire items relating to forest fire prevention attitudes, by metropolitan area, 1976

Item	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)	Item	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)
<i>Percent</i>					
The one place where people should be free from rules and regulations is when they're off in the woods. Do you agree or disagree? (6a)			And how good a job are they doing making the forests and wildland areas—enjoyable places for people to visit—excellent, good, fair, or poor? (7b)		
Agree	11.5	9.7	Excellent	26.1	21.1
Disagree	87.9	89.6	Good	53.2	59.1
No opinion	.3	.7	Fair	16.3	17.1
No answer	.3	—	Poor	3.4	1.1
			Don't know	1.0	1.1
The rules and regulations they have in forest areas are usually fair and reasonable. (6b)			Which of these do you think causes the most property damage in California every year? (8a)		
Agree	94.6	95.8	Floods	3.1	2.1
Disagree	2.7	3.5	Smog and air pollution	32.9	25.1
No opinion	2.7	.7	Forest fires	61.4	69.1
It would be a good idea to have more rangers to check up on forest visitors and make sure they abide by the forest regulations. (6c)			Landslides	.7	1.1
Agree	69.8	64.5	Earthquakes	1.4	—
Disagree	22.4	29.5	Don't know	.3	2.1
No opinion	7.1	6.0	No answer	.3	—
No answer	.7	—	Which do you think causes the next most damage? (8b) (Not asked unless "forest fires" was not given in 8a.)		
Some of the rules and regulations they have in forest areas are a lot stricter than they have to be. (6d)			Floods	2.0	2.1
Agree	13.2	17.9	Smog and air pollution	1.4	1.1
Disagree	81.4	77.4	Forest fires	31.2	23.1
No opinion	5.4	4.7	Landslides	2.0	—
Experienced campers and people with common sense generally don't have to pay much attention to forest regulations. (6e)			Earthquakes	1.0	1.1
Agree	35.6	30.8	Don't know	.3	—
Disagree	61.7	68.0	No answer	.3	—
No opinion	2.0	.7	Not asked	61.8	71.1
No answer	.7	.5	An occasional forest fire is part of nature's plan for renewing the land. Do you agree or disagree? (9a)		
These days, the rangers spend too much time enforcing rules that interfere with personal freedom. (6f)			Agree	52.5	56.1
Agree	8.1	8.4	Disagree	44.4	39.1
Disagree	83.5	84.2	No opinion	3.1	4.1
No opinion	8.1	7.2	No answer	—	—
No answer	.3	.2	Forest fires that start from natural causes should be allowed to burn if they don't threaten lives or private property. (9b)		
In your opinion, how good a job are government agencies doing in taking care of California's forests and wildland areas—excellent, good, fair, or poor? (7a)			Agree	21.4	23.1
Excellent	19.7	16.6	Disagree	74.6	71.1
Good	50.5	57.1	No opinion	4.1	4.1
Fair	19.0	22.6	No answer	—	—
Poor	6.4	1.5	On the average, fires probably do less damage to the forest than logging. (9c)		
Don't know	4.4	2.2	Agree	35.9	44.1
			Disagree	53.9	43.1
			No opinion	10.2	11.1
			No answer	—	—

Item	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)
brush fires are mostly a ce and do little real harm. (9d)		
	20.7	24.6
ee	74.6	71.0
inion	4.4	4.2
wer	.3	.2
done by forest fire is often rated by government agencies ok after the forests. (9e)		
	11.5	13.6
ee	79.7	75.3
inion	8.5	10.9
wer	.3	.2
ant for government agencies each forest fire as soon as they matter where it occurs. (9f)		
	83.4	78.2
ee	13.9	20.1
inion	2.4	1.5
wer	.3	.2
ny spent fighting forest fires is money well spent. (9g)		
	83.4	85.2
ee	13.9	13.6
inion	2.4	1.0
wer	.3	.2
h you've heard or read, do you ke number of major forest fires alifornia has gone up, gone down, and about the same over the years? PROBE: What would o best guess? (10)		
	38.6	40.0
ee	43.1	35.0
ee down	12.2	14.8
de	5.4	10.2
wer	.7	—
m a forest or grassland area nghe summer, I seldom think of dangers of a fire. Do you agree or disagree? (15a)		
	32.9	32.3
ee	66.1	67.0
inion	.3	.5
wer	.7	.2
se news stories about forest fires television or in the papers, I usually ownem very closely. (15b)		
	70.1	59.1
ee	28.5	39.5
inion	.7	1.2
wer	.7	.2

Item	Los Angeles metropolitan area (n=295)	San Francisco metropolitan area (n=403)
It really bothers me to see people smoking in a forest or grassland area during the dry season. (15c)		
Agree	84.4	78.7
Disagree	14.6	20.3
No opinion	.3	.5
No answer	.7	.5
The people in charge of the forests some- times exaggerate the danger of a fire to encourage visitors to abide by forest regulations. (15d)		
Agree	26.1	25.8
Disagree	71.2	69.7
No opinion	2.0	4.0
No answer	.7	.5
The rules they have in forest areas about smoking and campfires are much stricter than they have to be. (15e)		
Agree	8.5	6.7
Disagree	89.1	90.1
No opinion	1.7	3.0
No answer	.7	.2
It really bothers me to see people leave a campfire unattended, even for a few minutes. (15f)		
Agree	91.6	86.4
Disagree	6.4	12.4
No opinion	1.0	1.0
No answer	1.0	.2
Suppose you saw someone acting careless with cigarettes or a campfire in a forest. Do you think you would report them, say something to them, or let other people take care of it? (17)		
Report them	15.6	14.9
Say something to them	77.7	80.6
Let others take care of it	4.7	3.5
No answer	2.0	1.0
Suppose someone accidentally starts a forest fire through carelessness. Do you think he should be put in jail, made to pay a fine, given a warning, or just let go? (18)		
Put in jail	10.2	9.2
Pay a fine	66.0	65.7
Warning	14.6	18.9
Let go	1.0	1.0
No answer	4.1	3.0
Other	4.1	2.2

Table 9—Zero-order correlations, means and standard deviations of attitude, knowledge, and activity measures of Los Angeles and San Francisco metropolitan area respondents, 1976

Sample area and variable	Correlations						
	Regulations	Let Burn	Salience	Knowledge	Activity	Mean	S.D.
Los Angeles metro. area (n=295)							
Regulations	1.00					90.42	13.82
Let Burn	-.11	1.00				51.11	17.01
Salience	.33	-.09	1.00			89.55	16.12
Knowledge	-.16	-.06	.29	1.00		58.07	14.52
Activity	-.06	.03	-.07	.10	1.00	11.67	15.52
San Francisco metro. area (n=403)							
Regulations	1.00					89.56	13.38
Let Burn	-.18	1.00				53.62	17.69
Salience	.36	-.14	1.00			88.15	15.18
Knowledge	.11	.06	.10	1.00		58.63	15.19
Activity	-.01	.08	-.03	.04	1.00	14.79	20.46



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- . . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.
- . . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.
- . . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Folkman, William S.

1979. **Urban users of wildland areas as forest fire risks.** Res. Paper PSW-137, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A telephone survey of 1500 households in metropolitan Los Angeles and San Francisco was made to (1) determine extent of wildland use by residents of the two metropolitan areas, reasons for non-use, and the characteristics of users; (2) describe and analyze activities, knowledge, and attitudes of users which may contribute to their fire risk; and (3) assess selected communication channels for conveying forest fire prevention information to the residents of metropolitan areas. Wildland use was more prevalent among San Francisco households, but otherwise households in the two areas were similar. Visitor and nonvisitor households differed markedly in socioeconomic characteristics. Visitors proved aware of the fire problem and in favor of fire prevention efforts, but showed gaps in knowledge of appropriate behavior in fire-fragile wildlands. Television and billboards were most frequently recalled sources of fire prevention messages. Radio was seldom mentioned.

Retrieval Terms: fire prevention; urban visitor; fire risk; knowledge; attitudes; urban visitor characteristics.

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Folkman, William S.

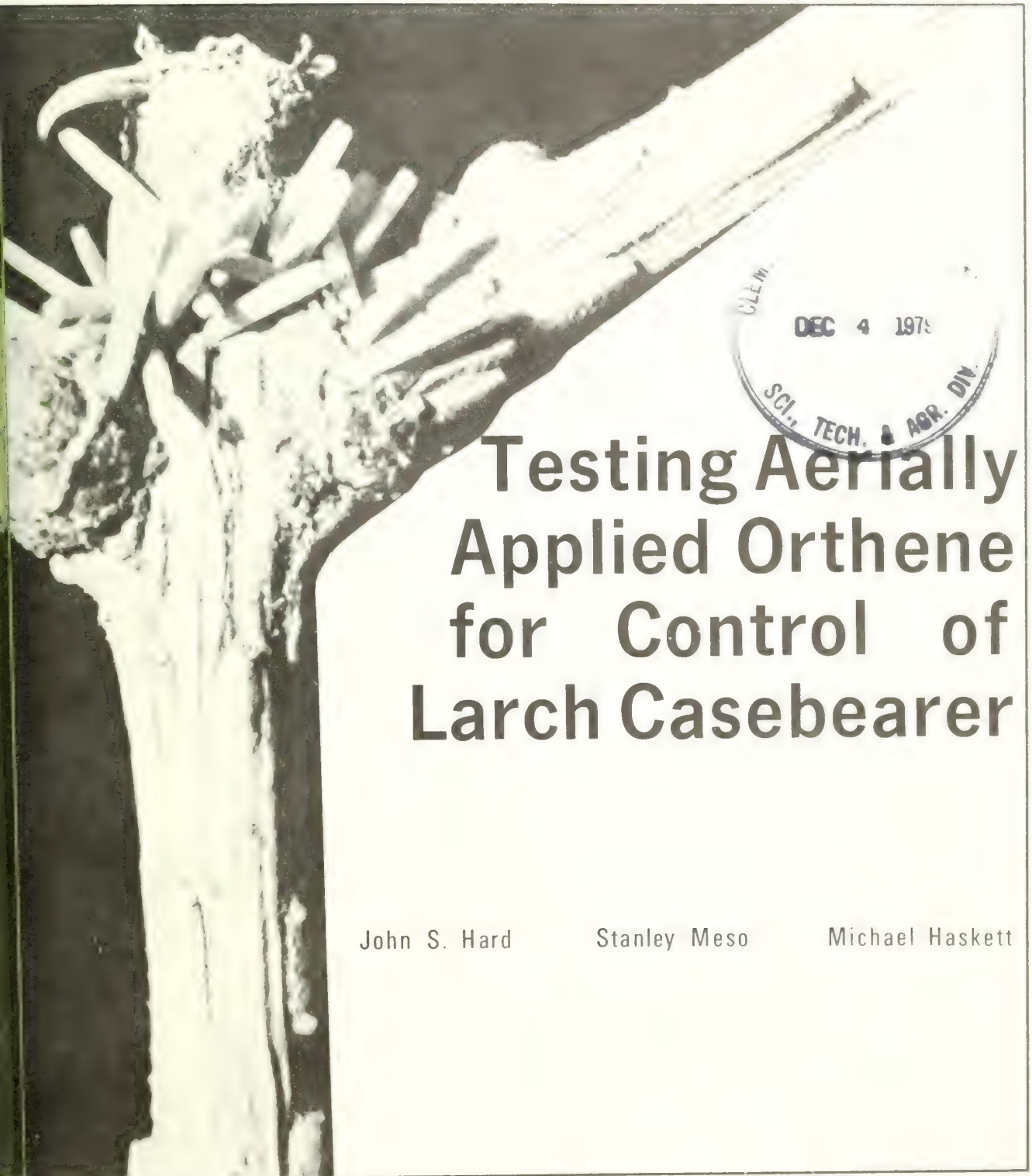
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PACIFIC SOUTHWEST Forest and Range Experiment Station

ST SERVICE
DEPARTMENT OF AGRICULTURE



Testing Aerially Applied Orthene for Control of Larch Casebearer

John S. Hard

Stanley Meso

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JOHN S. HARD was formerly an entomologist with the Station's research unit doing field evaluation of chemical insecticides, with headquarters in Davis, Calif. He is now assigned to the Forest Service's Northern Region, Missoula, Mont. He earned a forestry degree (1960) and a master of science degree in forest entomology (1962) at State University of New York, Syracuse. **STANLEY MESO** is an entomologist assigned to the Forest Service's Pacific Northwest Region, at Portland, Oreg. He earned a bachelor's degree in forest management at Purdue University (1952), and joined the forest Service in 1961. **MICHAEL HASKETT** is a biological technician with the field evaluation research unit, at Davis. A 1970 biology graduate of the University of Oregon, he joined the Forest Service in 1972 and the Station staff in 1976.



CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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We thank Glenn Parsons of the Boise Cascade Corporation, La Grande, Oreg., for providing test areas and support for the experiment; Roger Ryan of the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg., for identifying parasitoids collected from experimental areas; and David Sharpnack and Liz Maxwell of the Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif., for analyzing cost and variance data to determine optimum design for future insecticide field tests against the larch casebearer.

Testing Aerially Applied Orthene for Control of Larch Casebearer

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CONTENTS

Introduction.....	1
Materials and Methods	1
Results and Discussion	3
Conclusions	6
Literature Cited	6

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
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IN BRIEF ...

Hard, John S., Stanley Meso, and Michael Haskett.

1979. Testing aerially applied Orthene for control of larch casebearer.

Res. Paper PSW-138, 6 p., illus. Pacific Southwest Forest and Range
Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Retrieval Terms: insecticides; field tests; aerial spraying; Orthene; larch
casebearer; *Coleophora laricella* (Hbn.).

Orthene was applied by helicopter to larch casebearer *Coleophora laricella* (Hbn.) near LaGrande, Oregon, in September 1976. The object of the experiment was to test whether Orthene, applied at a rate of 0.5 lb/gal water/acre (560 g/9.3 l/ha) would reduce, but not annihilate larch casebearer larval populations, and would protect host trees from heavy defoliation the following spring.

A randomized block design with one 50-acre replicate of each of four treatments in each block was used. Spray deposit was sampled with Kromekote cards. Casebearer larval populations were sampled 1 day prespray and 6 weeks postspray, but parasitoid populations were not assessed until the following spring.

Spray deposits were uniform among spray treatments and there was a close relationship between postspray casebearer populations and spray deposits. Larval populations were reduced an average of 92.1 percent in treated plots and an average of 40.5 percent in check plots. There were no signifi-

cant differences in casebearer population reduction among the three treatment strategies. Defoliation index averaged light on treated plots and heavy on check plots the following spring; percent parasitization averaged 4.0 percent on treated plots and 1.3 percent on check plots.

We concluded that aerial application of 0.5 lb a.i./gal water/acre (560 g a.i./9.3 l/ha) to larch casebearer larvae provides adequate population reduction in young western larch stands and prevents heavy defoliation of trees the next spring. We recommend that no operational spraying be done in areas where parasitoids, such as *Agathis pumila* and *Chrysocharis laricinellae*, have been introduced until further research determines whether fall spraying of Orthene is detrimental to them.

Variances of larch casebearer percent population reductions and cost estimates of the various treatment and sampling tasks were analyzed for optimal experimental design in future larch casebearer insecticide field experiments.

Orthene (*O,S*-Dimethyl acetylphosphoramidothioate) is a cholinesterase-inhibiting insecticide whose common name is acephate. It effectively controls forest defoliators such as the Douglas-fir tussock moth *Orgyia pseudotsugata* (McDunnough) (Neisess and others 1976) and the western spruce budworm, *Choristoneura occidentalis* Freeman (Markin 1977). Orthene is a systemic insecticide¹ which shows some phloem mobility and is transported through plant tissues to internal feeding sites of insects such as needlemining larch casebearer *Coleophora laricella* (Hbn.).² Orthene aerially applied at a rate of 1 lb a.i. (active ingredient) in 1 gal of water per acre (1120 g a.i./9.3 l/ha) reduced needlemining casebearer populations in Idaho

almost 100 percent (Washburn and others 1977).

We experimented to determine whether Orthene applied aerially at a rate of 0.5 lb a.i./gal/acre (560 g/9.3 l/ha) near LaGrande, Oregon would reduce, but not annihilate larch casebearer larval populations, and would protect host trees from heavy defoliation the following spring. Low casebearer populations surviving the treatment were desired to support (1) native parasitoids and (2) introduced parasitoid species released in nearby areas (Ryan and others 1977).

This paper describes experimental procedures in detail and includes cost and variance data analyses to show optimum experimental design for future chemical field tests and pilot projects.

MATERIALS AND METHODS

Four rectangular 50-acre (20-ha) plots 1000 ft by 2178 ft (305 m by 664 m) were established in each of three areas at elevations ranging from 4000 to 4800 ft (1300 to 1600 m) approximately 24 km east of La Grande, Oregon. A total of 180 young western larch (*Larix occidentalis* Nutt.) were selected, 15 per plot, for casebearer larval and pupal population sampling and subsequent defoliation estimates. These trees were larch casebearer infested and open grown. Sample tree diameters, heights, and live crowns averaged, respectively, 5 inches (12.7 cm), 35 ft (10.7 m), and 90 percent of total height.

We used a randomized block experimental design with one replicate of each of four treatments in each block. Treatments were aerially applied Or-

thene 75S³ (75 percent soluble powder) water solutions of 0.5 lb a.i./gal/acre (560 g a.i./9.3 l/ha) on three plots in each block and one randomly assigned untreated check. Spray sequence in each block was randomly assigned. The spray formulation contained 10 percent (by volume) ethylene glycol to reduce evaporation and to improve spray atomization, and 3.78 g/gal (1 g/l) of Rhodamine B Extra S (GAF) dye to aid in spray deposit assessment.

We sprayed all treated plots within a block on the same morning, but treated each block on a separate date—block 3 on September 9, block 1 on September 12, and block 2 on September 13, 1976. Crews monitored and recorded temperature, relative humidity, and windspeed in each plot during spray application. Spray conditions were generally good, with cool temperatures, high humidities, and little

¹Lyon, R. L. 1973. *Reports from the Insecticide Evaluation Project, PSW-2203*. USDA Forest Serv., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 5 p.

²Page, Marion, Richard I. Washburn, and Nicholas L. Crookston. *Systemic effect of acephate on specific densities of needlemining larch casebearer in the laboratory*. (Manuscript in preparation.)

³Trade names and commercial products and enterprises are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied. This publication reports research involving pesticides. It neither contains recommendations for their use, nor does it imply that the uses discussed have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

or no wind on all 3 spray days. Light rain fell on September 12 near the end of spraying, but amounted to only a trace of precipitation.

We marked plot corners with colored treetop banners for spray pilot guidance and orientation. A Bell 206 Jet Ranger helicopter flying 60 mph (97 kph) 50 ft (15 m) above the trees applied the spray at 40 psi (2.8 kg/cm²) in 70-ft (21-m) swaths parallel to the long axis of each plot. The spray system consisted of a detachable belly tank with conventional boom and 43 evenly-spaced flat fan T8002 tips (Spray Systems, Wheaton, Ill.).³

One 4- by 4-inch (10- by 10-cm) Kromekote card was placed in the open at ground level near each sample tree on treated plots to sample spray deposit. Kromekote cards were also placed near trees in untreated plots to detect spray drift from treated plots. We used a Quantimet Image Analyzer with a 32-mm objective lens to measure and count all droplets greater than 91 μ in diameter in a 42-cm² area on each card. Spray droplet volume median diameter (VMD), mean number of droplets per cm², and gallons per acre (GPA) of spray deposited on each treated plot were computed by using a modified U.S. Army data processing system (ASCAS).

We sampled prespray larval populations 1 day before spray, and postspray larval populations 6 weeks later to determine effects of Orthene on casebearer, but did not assess parasitoids until the following spring. One branch from the upper crown third, two branches from the midcrown third, and one branch from the lower crown third comprised each tree sample at each sample period. We clipped six 6-inch (15-cm) twigs—minus current year's terminal shoot growth from the distal portion of each sample branch—and counted larvae on all needle fascicles of randomly selected 6-inch twigs until a total of 50 fascicles were examined on each sample branch. Each needle of each sample fascicle was examined by using transmitted light and a stereomicroscope to determine presence of live needlemining larvae during the prespray larval counts. We counted overwintering larvae, which were easily seen on postspray sample twigs through a stereomicroscope, on the first 50 fascicles of randomly selected 6-inch twigs from each sample branch.

Individual indices of sample tree defoliation were computed according to procedures described by Ciesla and Bousfield (1974) from visual defoliation estimates recorded in June 1977. In addition, aerial photographs were taken of treated plots and surrounding untreated areas by using color

infrared film to detect differences in defoliation intensity.

We sampled larch casebearer pupal populations in June 1977 to assess any differences in rate of parasitization between Orthene-treated and untreated plots. We placed 100 pupae bearing fascicles from two midcrown branches of each sample tree in a 2-quart (1.89-l) ice cream carton with moistened cotton and reared larch casebearer moths and parasitoids. The parasitoids were identified as to species. Parasitoid species are vertically stratified in larch crowns (Tunnock and others 1972), but we assumed that midcrown samples would provide an index of parasitization by all species.

Mean and standard error of prespray and post-spray larvae per 100 fascicles, percent mortalities, deposit indices, and tree defoliation indices for each sample plot were computed. Analyses of variance were done to detect significant differences among blocks and among treatments. We also computed pooled variances by treatment to assess to what degree the experiment was able to detect truly significant differences among treatments (Pearson and Hartley 1951).

Regression analyses were used to graph relationships of plot sample mean (1) larch casebearer larval numbers per 100 fascicles at midcrown over (a) larval numbers per 100 fascicles at all three crown levels, and over (b) spray deposit in gallons per acre; (2) percent larval mortality at midcrown over spray deposit in drops per cm²; and (3) defoliation index over larval numbers per 100 fascicles at midcrown.

We computed regressions as if independent (X) variables had been measured without sampling error. The sample regression coefficients, therefore, may be biased estimates of the true population regression coefficients (Snedecor and Cochran 1967). The measurement errors in X are little more than 10 percent of the total range of X-values in any regression, however. We therefore consider the expressed degrees of correlation between the various X and Y variables to be realistic and the equations describing the relationships to be reasonable approximations of the true relationships (Daniel and Wood 1971).

Variances of larch casebearer percent population reductions and cost estimates of the various treatment and sampling tasks were analyzed for optimum experimental design in future larch casebearer insecticide field experiments or pilot projects.

RESULTS AND DISCUSSION

Spray deposits were uniform among spray treatments (*table 1*) and efficacies of the three spray treatments were comparable (*fig. 1*).

We found no significant differences in prespray casebearer larval numbers among treatments, but found highly significant differences in postspray larval numbers, percent larval mortalities, and defoliation indices between sprayed and check plots (*table 2*).

Midcrown sample larval means were representative of larval means from all three crown levels (*fig. 2*), and the linear relationship between midcrown sample larval means and all crown level larval means (*fig. 2*) was about one-to-one and intercepted the graph near zero. Midcrown larch casebearer larval population densities were also representative of mean larval population densities in eastern larch (Webb 1953). Because of the one-to-one relationship between midcrown sample larval means and all crown level means, as well as the high degree of correspondence between midcrown population densities and mean larval population densities, midcrown sampling can be considered appropriate for efficacy tests of Orthene against larch casebearer.

Close relationships occurred between mean postspray casebearer larval numbers in midcrown samples and mean spray deposit in gallons per acre (*fig. 3*), and mean percent larval mortality in midcrown samples and spray deposit in drops per cm² (*fig. 4*). Spray deposit measured in drops per cm² appeared low (*table 1, fig. 4*), but many drops smaller than 91 μ were deposited but not recorded when scanned by the image analyzer.

The linear relationship between mean sample tree defoliation index and mean number of postspray larvae in midcrown samples (*fig. 5*) is steeper than the relationship reported by Ciesla and Bousfield (1974). Their samples were taken in mature untreated western larch stands, whereas ours were taken in young treated stands. On the basis of 15 sample tree estimates in each plot, we found one

treated plot was undefoliated, six treated plots were lightly defoliated, two treated plots were moderately defoliated, and all three check plots were heavily defoliated the spring following treatment. We could not distinguish defoliated from undefoliated areas on the aerial photos, because the plots contained western larch mixed with true fir, Douglas-fir, ponderosa pine, and lodgepole pine and many lodgepole pines were discolored by a foliage disease.

Larch casebearer pupal parasitoids were not abundant in the experimental plots, but percent parasitism was higher in treated plots than in check areas, and species compositions were comparable among treatments (*table 3*).

As we expected, casebearer percent mortality variances among plots were higher than mortality variances within or among trees. Because of this difference, future insecticide tests comparing two or more chemicals or two or more dosages of a single chemical will be logistically difficult and prohibitively expensive (*table 4*), unless experimental objectives are modified. Rather than test the data to determine whether percent mortalities resulting from two treatments are statistically different, perhaps a test to show which of the treatments equalled or exceeded a prescribed level of control would be less costly.

A pilot control project to compare two treatments (chemical against chemical or chemical against check), where the expected difference in percent mortality between treatments is about 50 percent, would require only three plot pairs, and the cost would be dependent on the number of acres sprayed and the experimental power selected to detect that mortality differences were truly significant (*table 4*). Because the difference in percent mortality between a chemical treatment and a check treatment could be less than 50 percent, we suggest that four plot pairs be used if logistically possible.

Table 1—Sample spray deposit indices, by treatment

Treatment	Mean deposit and standard error ¹		
	Drops/cm ²	Volume median diameter μ	Gal/acre
Sprayed first	5.85 $\pm$ 0.92	306.6 $\pm$ 24.1	0.43 $\pm$ 0.09
Sprayed second	6.92 $\pm$ 2.41	343.5 $\pm$ 13.4	0.60 $\pm$ 0.10
Sprayed third	5.72 $\pm$ 0.50	363.2 $\pm$ 20.6	0.60 $\pm$ 0.09

¹ Computed from three replicate averages per treatment.

Table 2—Significance of casebearer mean larval numbers, mean percent mortality, and mean defoliation index on *Orthene* field test experimental plots¹

Treatment	Larval numbers per 100 fascicles		Mortality	Defoliation index ²
	Prespray	Postspray		
			<i>Percent</i>	
Sprayed first	157.4	10.6	93.2	16.1
Sprayed second	173.0	18.6	91.4	19.0
Sprayed third	171.1	15.4	91.8	16.3
Untreated	217.4	123.9	40.5	61.5
Range	60.0 ³	113.3	52.7	45.4

¹Means not connected by a vertical bar are significantly different at the 99 percent level.

²Negligible = 0 to 8.9, light = 9.0 to 26.9, moderate = 27.0 to 44.9, heavy = 45 or greater.

³The experimental power—percent chance of detecting a truly significant difference as high as the ranges shown between treated and untreated plots—is as follows: For prespray range of 60.0, <20 percent chance at the 95 percent level, <20 percent chance at the 99 percent level; for postspray range of 113., >99 percent chance at the 95 percent level, 89 percent chance at the 99 percent level; for mortality range of 52.7, >99 percent at the 95 percent level, 89 percent chance at the 99 percent level; for defoliation index of 45.4, 97 percent chance at the 95 percent level, 82 percent chance at the 99 percent level.

Table 3—Parasitoids reared from larch casebearer pupae collected June 1977 from experimental plots treated with *Orthene* in S 1976

Parasite species	Treatment		
	Sprayed first	Sprayed second	Sprayed third
Eulophidae:			
<i>Tetrastichus</i> sp.	4	0	2
<i>Derostenus silvia</i>	7	9	10
<i>Elachertus</i> sp.	4	0	0
<i>Dicladocerus nearcticus</i>	1	0	1
<i>Cirrospilus</i> (?) sp.	0	1	0
Pteromalidae:			
<i>Mesopolobus verditer</i>	1	0	2
<i>Habroclytus phycidis</i>	0	1	0
Unknown species	0	0	1
Chalcididae:			
<i>Spilochalcis albifrons</i>	5	5	7
<i>Spilochalcis leptis</i>	2	0	0
Ichneumonidae:			
<i>Itoplectis evetriae</i>	9	3	4
Unknown species	0	0	0
Braconidae:			
<i>Bracon pygmaeus</i>	4	1	0
Total	37 (780) ¹	20 (459)	27 (978)
Parasitization	Percent		
	4.7	4.4	2.8

¹ Numbers in parentheses represent numbers of casebearer pupae in rearing.

Table 4—Optimum sampling requirements and estimated costs for randomized block field tests of insecticide treatments to larch casebearer needlemining populations

Alternate hypothesis: Percent difference in average mortality between treatments ¹	Treatments	Plots per treatment	Trees per plot	Branches per tree ²	Experimental power ³	Costs ⁴
					Percent	Dollars
50 percent	2	3	17	2	90	3,590
	2	3	9	2	80	2,974
	2	3	6	2	71	2,743
10 percent	2	14	19	2	80	17,474
	2	11	23	2	70	14,859
	2	10	18	2	60	12,224
20 percent between one pair and 10 percent between another pair ⁵	3	8	15	2	90	13,745
	3	7	13	2	81	11,487
	3	6	13	2	71	9,845

Percent difference in average mortality between treatments where differences between a number of insecticides or between a number of insecticides and a check, are being tested.

¹Analysis using two, four, and six branches showed that the desired power always met minimum cost requirements with two branches.

³Experimental power is the percent chance of detecting a truly significant mortality difference of the magnitude stated in the alternate hypothesis.

⁴Based on temporary employee salary costs of \$4.45 per hour, spray application costs of \$5.00 per acre on 60-acre (24-ha) plots, and spray card reading costs of \$2.00 per card; does not include salary or travel costs of permanent personnel.

⁵These percent differences are not additive. The maximum range of differences is 20 percent; therefore, the maximum difference between any two of the three treatments is 20 percent.

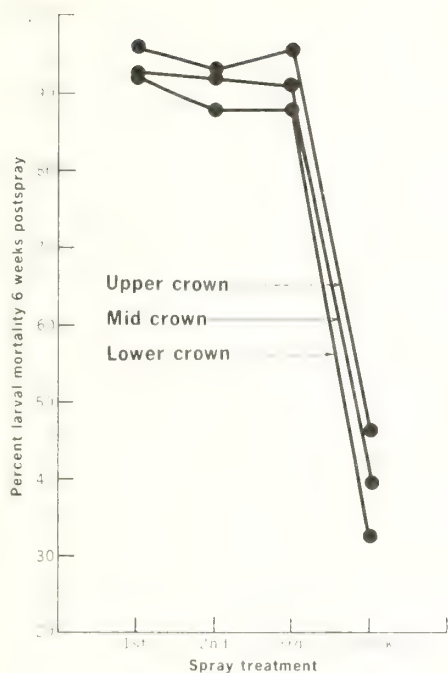


Figure 1—Percent larch casebearer larval mortalities in midcrown samples approximate percent mortalities in combined samples of all tree crown levels.

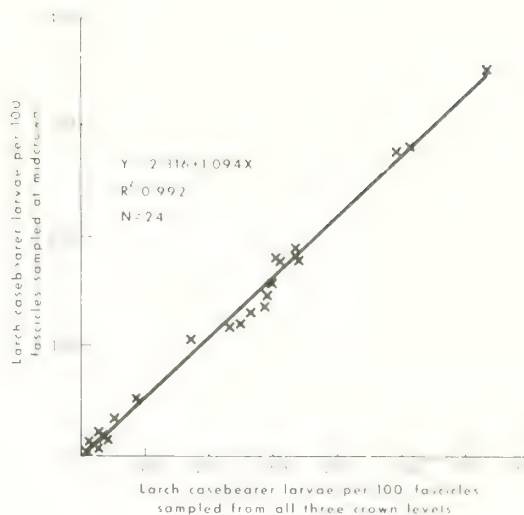


Figure 2—Midcrown sample mean larch casebearer larval numbers are approximately equal to total crown sample mean larval numbers in pre- and postspray samples.

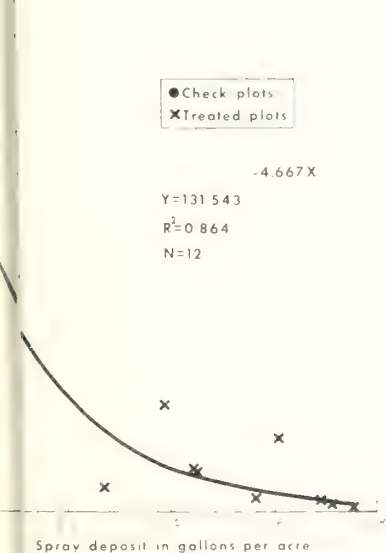


Figure 3—Midcrown sample mean larval numbers postspray samples are closely associated with Orthene spray deposit measured in gallons per acre.

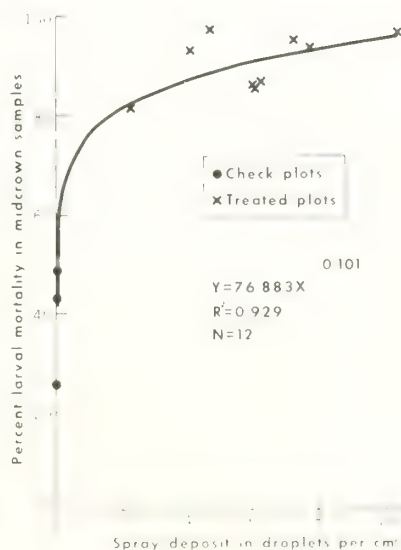


Figure 4—Percent postspray larval mortality in midcrown samples is closely related to Orthene spray deposit in drops per cm².

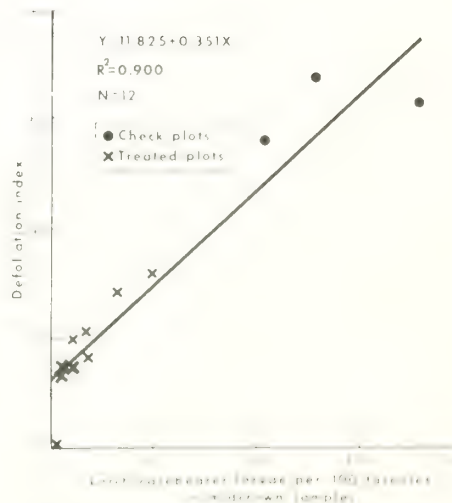


Figure 5—Sample plot defoliation index is closely related to postspray larval numbers in midcrown samples.

CONCLUSIONS

Helicopter application of 0.5 lb Orthene in 1 gallon water per acre (560 g a.i./9.3 l/ha) to needlemining larch casebearer larvae provides significant population reduction in young western larch stands and protects the trees against heavy defoliation the following spring. Native parasitoids emerging from larch casebearer pupae do not appear to be adversely affected by a fall application of 0.5 lb Orthene per acre (560 g a.i./ha).

We conclude that midcrown sampling is appropriate for casebearer larval sampling in future chemical efficacy tests. We do not know what effect Orthene spraying may have on introduced parasitoids, such as *Agathis pumila* and *Chrysoschelis laricinellae*. We recommend that no operational spraying of Orthene be done in areas where these species have been released until further research determines whether fall spraying of Orthene affects them detrimentally.

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Retrieval Terms: insecticides; field tests; aerial spraying; Orthene; larch casebearer.

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Growth and Mortality of Thinned Knobcone X Monterey Pine Saplings Affected by Engraver Beetles and a Hard Freeze

William W. Oliver



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CONTENTS

	<i>Page</i>
Introduction	1
Plantation	1
Methods	3
Results and Discussion	3
Mortality	3
Growth	6
Conclusions	8
Literature Cited	9

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IN BRIEF...

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Retrieval Terms: *Pinus attenuata* × *Pinus radiata*, growth, mortality, thinning, *Ips paraconfusus*, freeze damage

The knobcone (*Pinus attenuata* Lemm.) × Monterey pine (*P. radiata* D. Don) is a drought-hardy, fast-growing hybrid, popular for stabilizing soils and screening campgrounds. The hybrid seems suited, also, to produce roundwood on a short rotation, especially on marginal timber sites. Stand management techniques have been little known, however. This paper reports the growth and mortality of an 8-year-old knobcone × Monterey pine plantation 5 years after thinning to three different spacings and 4 years after a hard freeze.

The plantation lies at 3200 feet (976 m) elevation on a steep east-facing slope in the Klamath Mountain Province of northern California. Summers are dry and hot and winters are moist and cool, with temperatures seldom below 10° F (−12° C).

In February 1964, about 5 acres (2 ha), cleared of dense chaparral, were planted with 1-0 stock. Early survival and growth was extraordinary. Eight growing seasons later, in the fall of 1971, crowns had closed and intertree competition was intense when the stand was thinned from below. For the thinning study, three spacing treatments were assigned randomly to two each of six 0.1-acre (0.04-ha) plots. Spacings were 8 by 8 feet (2.4 by 2.4 m), 12 by 12 feet (3.7 by 3.7 m), and 16 by 16 feet (4.9 by 4.9 m).

By July 1972, 8 months after thinning, the California five-spined engraver (*Ips paraconfusus*) had killed 15 percent of the trees. Mortality was evenly distributed throughout all plots and was not related to spacing. No trees died from engraver attacks after July 1972. Apparently, the engraver population reached epidemic levels by breeding in slash during the winter and early spring—an unusual occurrence.

Beginning on December 8, 1972, one growing season after thinning, northern California was gripped by severe cold. Minimum temperatures of between 0° F and −10° F (−18° C and −23° C) for 4 days created the most severe conditions in 40 years. The foliage of most trees was injured and 20 percent of the trees were killed, apparently from winter desiccation. Again, no pattern was discernible among treatment plots. As expected, however, mortality was concentrated in trees with greater foliar damage.

The engraver and the freeze accounted for all mortality in the 5 years since thinning. Although a few more trees died in the plots with narrower spacings, the proportion of trees killed by both the engraver and freeze increased with wider spacing from 17 percent for trees spaced 8 by 8 feet (2.4 by 2.4 m) to 48 percent for trees spaced 16 by 16 feet (4.9 by 4.9 m).

Diameter growth of the average tree surviving the freeze was reduced significantly the following year. Trees that had been growing 0.50 inch (1.3 cm) in diameter before the freeze grew only 0.20 inch (0.5 cm) the year following—a 60 percent drop. The duration of reduced diameter growth cannot be determined, however. Certainly the decline in growth lasted 2 years. But the third and fourth years after the freeze, growth leveled off at a rate well below that before the freeze. Failure of diameter growth to return to pre-freeze rates may have been caused by (a) secondary agents attacking freeze-weakened trees, (b) below-normal precipitation, (c) intertree competition, or (d) age.

Severity of freeze damage also influenced the amount of subsequent diameter growth. As expected, trees on which a greater proportion of the needles had turned brown grew less rapidly following the freeze than did those with a smaller proportion of brown needles.

Mortality and residual effects of the freeze may have overshadowed the influence of spacing on most growth measures. Diameter growth, however, was strongly influenced by spacing. Trees grew 0.28-inch (0.7-cm) annually when spaced 8 to 9 feet (2.4 to 2.7 m) apart to 0.48-inch (1.2-cm) when spaced 14 to 22 feet (4.3 to 6.7 m) apart.

Freeze damage and mortality must be considered in the management of knobcone × Monterey pine plantations if temperatures as low as −10° F (−23° C) can be expected at the planting site. Precommercial thinning probably would not have been necessary or desirable if trees had been planted to a 6- or 8-foot (1.8- or 2.4-m) spacing. Freeze mortality would have provided adequate thinning.

The pine hybrid knobcone (*Pinus attenuata* Lemm.) × Monterey pine (*P. radiata* D. Don) was produced first in 1939 (Stockwell and Righter 1946). Since then, many small exploratory plantings demonstrate that the hybrid inherits much of the drought and frost hardiness of the knobcone pine and the spectacular juvenile growth of the Monterey pine. These attributes have created a demand for about 50,000 seedlings per year (Kitzmilller 1976). Present uses for the hybrid are for erosion control and screening of recreation areas. The tree seems suited, also, for roundwood production on very short rotations, especially on marginal timber sites.

We know little about the performance of knobcone

× Monterey pine stands. Information on the optimum spacing for wood production is particularly needed. But because no managed stands of the hybrid have been studied, observations of unmanaged stands of knobcone pine and experience with Monterey pine as an exotic in the southern hemisphere provide the only guidelines.

An opportunity to explore spacing-growth relationships arose when a plantation of knobcone × Monterey pine saplings, 9 years old when thinned in 1971, was severely damaged a year later by an unusual cold wave.

This paper reports the growth and mortality on study plots in this stand, 5 years after thinning to three different spacings and 4 years after the freeze.

PLANTATION

The plantation, administered by the U.S. Bureau of Land Management, lies at 3200 feet (976 m) elevation in the Klamath Mountain Province, 4.5 (7.2 km) miles southeast of Douglas City, Trinity County, California. It extends from the top to midslope on the east side of a narrow spur ridge jutting from a broad south slope (*cover*). The steepness of the convex slope is 40 to 70 percent. The Spring Gulch Plantation (Griffin and Conkle 1967), designed to evaluate the hybrid produced from southern Oregon sources of knobcone pine, is about 200 feet (61 m) distant along the same narrow ridge. The soil, a deep clay loam overlying Pre-Silurian mica schist, is now classified as Orn Series, an Ultic Haploxeralf (U.S. Dep. Agric. Soil Conserv. Serv. 1975).

The area has hot, dry summers with negligible rainfall between June and October. Weaverville, the nearest weather station, 8.8 miles (14.1 km) northwest and 1200 feet (366 m) lower in elevation than the plantation, reports mean maximum August temperatures of 94° F (34° C) with many days exceeding 100° F (38° C). Winters are cool and wet with about 50 inches (1270 mm) of precipitation, 10 percent of which falls as snow especially in January. In Weaverville, January temperatures include a mean minimum of 27° F (-3°

C), a mean maximum of 47° F (8° C), and an extreme low of -7° F (-22° C). At the plantation, however, winter temperatures probably never dropped below 10° F (-12° C) until 1972.

Dense chaparral, mostly chamise (*Adenostoma fasciculatum* H. & A.) and green leaf manzanita (*Arctostaphylos patula* Greene), was cleared from the site the year before planting. Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and evergreen hardwoods grow in the draws but the slopes and ridge tops probably were never well-forested. Site index based upon height intercept of ponderosa pine (*Pinus ponderosa* Laws.) planted nearby is 50 to 55 feet (15 to 17 m) at 50 years (Powers and Oliver 1978).

In February 1964, the Redding District, U.S. Bureau of Land Management, hand planted about 5 acres (2 ha) with 1-0 stock. The hybrids were produced from native knobcone pines growing at Pennsylvania Point on the Eldorado National Forest, and Monterey pines of unknown origin growing at the Institute of Forest Genetics at Placerville, both in El Dorado County, California. The seedlings were closely planted at about 4 by 4 feet (1.2 m).

Early survival and growth were extraordinary: over 90 percent of the planting stock survived, and three

growing seasons after planting the average tree was 5 feet (1.5m) tall. By the fall of 1971, eight growing seasons after planting, crowns had closed and intertree competition was intense. Trees averaged 14 feet (4.3 m) tall and 2 inches (5 cm) d.b.h. (table 1).

Heavy, wet snow, common at this elevation, bent the trees each winter, but until the winter of 1970-71, most stems straightened out the following growing

season. The snow damage that year was so severe that many trees did not recover because they were bent horizontal and root sprung. Damage was largely confined to the most densely stocked areas. The decision to thin the stand in fall 1971 was based on a desire to lessen growth losses and snow damage from high stand density.

Table 1 —Stand characteristics before and after thinning of 9-year-old knobcone × Monterey pine saplings

Time period, spacing treatment (ft), and plot	Trees per acre	Average d.b.h.	Average height	Basal area	Net volume ¹
		<i>Inches</i>	<i>Ft</i>	<i>Ft²/acre</i>	<i>Ft³/acre</i>
Before thinning:					
4 by 4					
5	1980	2.22	15.4	53.2	415
6	2030	1.72	12.9	32.8	222
2	2160	2.11	15.0	52.3	391
3	2100	2.16	15.4	53.7	400
1	2660	1.92	13.4	53.6	382
4	2090	2.16	15.3	53.4	400
After thinning:					
8 by 8					
5	700	2.72	19.1	28.3	247
6	680	2.16	14.8	17.4	126
12 by 12					
2	330	2.68	19.9	12.9	114
3	330	2.75	18.0	13.9	125
16 by 16					
1	170	2.78	19.5	7.1	62
4	180	2.90	20.0	8.3	78
Two years later:					
9 by 9					
5	570	3.31	22.3	34.1	356
6	580	2.78	17.6	24.4	218
14 by 14					
2	230	3.34	23.8	14.0	135
3	210	3.48	21.3	13.8	148
22 by 22					
1	90	3.76	23.4	7.0	75
4	90	3.84	23.5	7.2	76
Five years later:					
9 by 9					
5	570	4.11	26.4	52.4	610
6	580	3.49	20.9	38.5	374
14 by 14					
2	230	4.41	27.6	24.4	263
3	210	4.49	24.9	23.1	266
22 by 22					
1	90	5.19	26.4	13.2	155
4	90	5.24	25.8	13.5	140

¹Gross volume (inside bark from 1-foot stump to tip) less mortality.

METHODS

Before the largest planting of about 3.5 acres (1.4 ha) was thinned to an 8- by 8-foot (2.4 m) spacing, we installed six 0.1-acre (0.04-ha) study plots. Each of three spacing treatments was randomly assigned to two of the six plots. The spacings—8 by 8 feet (2.4 m), 12 by 12 feet (3.7 m), and 16 by 16 feet (4.9 m)—span the recommendations of many investigators working with Monterey pine 5 to 10 years old as an exotic in the southern hemisphere (Roy 1966).

The plots were thinned by the usual standard: the most vigorous, well-formed dominant and codominant trees were left, as far as possible with reasonable uniform spacing. Slash was not treated because the trees were small and their branches limber.

Immediately after thinning, each tree was tagged, measured, and described. Diameter at breast height to the nearest 0.1 inch (0.25 cm) was recorded for all

trees. Twenty percent of the trees, randomly assigned on each plot, were measured for total height, crown length, and crown width, all to the nearest 1 foot (0.3 m). Total stem volume was estimated for each plot from detailed stem measurements of 10 trees. These trees were chosen with probability proportional to size. Upper stem diameters and lengths were measured directly. Stem volumes inside bark from a 1-foot (0.3-m) stump to tip were calculated by Grosenbaugh's (1967) STX computer program. Plots were remeasured outside the growing season 2 and 5 years after thinning (1973 and 1976). Also at the 5-year remeasurement, an increment core was extracted from every fifth tree or at least five trees in each plot to determine annual diameter growth. Stand characteristics were calculated from plot data on an acre basis (table 1).

RESULTS AND DISCUSSION

Mortality

The California five-spined engraver (*Ips paraconfusus* Lanier) and a hard freeze accounted for all mortality in the plots in the 5 years since thinning. Although a few more trees died in plots with narrower spacings, the proportion of trees killed by both the engraver and the freeze increased with wider spacing

from 17 percent for trees spaced 8 by 8 feet to 48 percent for trees spaced 16 by 16 feet (table 2, fig. 1). This relationship was highly significant ($p \leq 0.01$). Total mortality per plot, for plots thinned to the same spacing, was similar and uniformly distributed, and resulted in spacings of 9 by 9, 14 by 14, and 22 by 22 feet (2.7, 4.3, and 6.7 m) for the surviving trees.

Table 2—Mortality of knobcone $\times$ Monterey pines as result of attack by *Ips paraconfusus* followed by a hard freeze

Spacing treatment (feet) and plot	Original number of trees	Trees killed by <i>Ips</i> , spring 1972	Surviving trees killed by freeze December 1972	Total mortality ¹	Resultant spacing
		Pct	Pct	Pct	Feet
8 by 8					
5	70	4	15	19	9 by 9
6	68	6	9	15	9 by 9
12 by 12					
2	33	18	15	30	14 by 14
3	33	15	25	36	14 by 14
16 by 16					
1	17	41	10	47	22 by 22
4	18	6	47	50	22 by 22
Mean		15	20	26	

¹Percentages are not additive because they are based upon different numbers of trees.

A**B**

Figure 1—When photographed, these nine-year-old knobcone $\times$ Monterey pines had just been thinned (A) in Plot 6 to an 8-foot spacing, and (B) in Plot 4 to a 16-foot spacing. Five years later, engraver beetles



and a hard freeze had killed (C) 15 percent of the trees in Plot 6, leaving survivors at a 9-foot spacing, and (D) 50 percent of the trees in Plot 4, leaving survivors at a 22-foot spacing.

Engraver Beetle

The engraver beetle killed 15 percent of the leave trees by July 1972—8 months after thinning. As few as 4 percent of the trees died in one plot spaced 8 by 8 feet and as many as 41 percent in another spaced 16 by 16 feet (*table 2*). Mortality was evenly distributed throughout all plots and tended to be higher in plots with trees at wider spacings. This trend was not statistically significant ($p > 0.05$), however. No trees died from engraver attack after July 1972.

Apparently the engraver population, breeding in slash during the winter and early spring after thinning, reached epidemic levels. This was unusual, but the California five-spined engraver is notoriously unpredictable. Thinning in the fall is encouraged (Struble and Hall 1955) because usually the engraver overwinters in small numbers and cannot reach a high population before slash dries out the following spring. Similar rare outbreaks have been attributed to warm, dry winters. But during the winter of 1971-72 as reported at Weaverville, temperatures were below normal and rainfall was only slightly below normal—4 inches (102 mm) below the normal of 25 inches (635 mm) between December and July. Leaving the slash unlogged may have contributed to the outbreak.

Freeze

Beginning on December 8, 1972, one growing season after thinning, northern California was gripped by 5 days of severe cold. Minimum temperatures at Weaverville, the lowest in 40 years, were -7°F (-22°C) on December 8, and -10°F (-23°C) on December 9, and did not rise above 0°F (-18°C) until December 12.

In March 1973, foliage of most trees on the plots was brown. Some buds and exposed branchlets were dead, also. Apparently it was winter desiccation—a common injury associated with low night-time temperatures and sunny days. Monterey pine plantations along the coast of northern California suffered similar damage during the freeze (Hood 1975). I rated the damage by a four-point scheme:

- 1 - no apparent damage
- 2 - <50 percent of the needles brown
- 3 - >50 percent of the needles brown
- 4 - all needles brown

By the end of the first growing season following the freeze, 20 percent of all trees within the plots had died (*table 2*). Again, no pattern was discernible. Mortality ranged from 9 to 47 percent, was dispersed throughout each plot, and was not significantly related to either spacing or tree size. Genetic variability may have overriden other influences. In Monterey pine, cold hardiness is highly variable (Hood 1975).

As expected, mortality was concentrated in trees with the higher damage ratings. Eighty-five percent of the trees in injury category 4, and 25 percent of those in category 3, had died. Death of trees less severely damaged was negligible.

Growth

Following the engraver beetle attack and hard freeze, most trees that survived grew more slowly in diameter. Residual effects of the freeze and, to a lesser extent, close spacing seemed to have caused the loss in growth.

Freeze Effects

Diameter growth of the average tree surviving the freeze was reduced significantly the year following. Trees that had been growing 0.50 inch (1.3 cm) in diameter, on the average, for the 2 years before the freeze grew only 0.20 inch (0.5 cm) the year following—a 60 percent drop (*table 3*). The second year, trees grew 0.27 inch (0.7 cm) on the average—better than the first year but still significantly less than before the freeze. Diameter growth in the third growing season increased to 0.35 inch (0.9 cm) and remained at about the same rate the fourth year. This rate was still significantly lower than that before the freeze.

Severity of freeze damage influenced the amount of subsequent diameter growth. As expected, trees with greater damage grew less rapidly following the freeze than did those less severely damaged, regardless of spacing.

Trees given damage rating 1 (undamaged) grew 0.32 inch (0.8 cm) the first year after the freeze (*table 3*). This drop to only 63 percent of the prefreeze rate was significant, statistically. Diameter growth increased slightly the second year and again the third year, stabilizing at 77 percent—rates significantly different from that before the freeze.

Diameter growth of trees given damage rating 2 fell significantly the first year to 0.21 inch (0.5 cm)—only 43 percent of its prefreeze rate. The second year following the freeze, growth increased to 55 percent of the prefreeze rate, but trees in all spacings were still growing significantly more slowly in diameter than they were before the freeze. During the third and fourth years, growth was about 70 percent of, and significantly below, the prefreeze rate.

Trees given damage rating 3 grew most slowly the year after the freeze—only 0.09 inch (0.2 cm). The second year, diameter growth more than doubled but was still only 45 percent of that before the freeze. During the third and fourth years, growth increased

Table 3—Mean annual diameter growth¹ by damage rating of knobcone × Monterey pines before and after thinning and a hard freeze

Damage rating ²	Annual diameter growth					
	1971 (before thinning)	1972 (after thinning, before freeze)	1973	1974	1975	1976
	<i>Inches</i>					
1 (n = 12)	0.48a	0.53a	0.32b	0.34b	0.39ab	0.39ab
2 (n = 26)	.48a	.50a	.21b	.27c	.36d	.33d
3 and 4 (n = 17)	.48a	.49a	.09b	.22c	.29c	.26c
Mean (n = 55)	.48a	.51a	.20b	.27c	.35d	.32d

¹ Diameters followed by the same letter in the same row are not significantly different at the 5 percent level

² Damage was rated by a four-point scheme:

1 = no apparent damage, 2 = <50 percent of the needles brown,

3 = >50 percent of the needles brown, 4 = all needles brown.

nonsignificantly to 57 percent of the prefreeze rate.

Duration of the reduced diameter growth following the freeze is not clearly evident. Certainly the dramatic decline in diameter growth lasted 2 years, at least. In the third and fourth years after the freeze, growth leveled off within each spacing and damage rating. But the rate was well below that before the freeze, especially in trees of damage rating 3. Probably, freeze damage, aided by secondary agents attacking freeze-weakened trees, suppressed growth longer than 2 years. For example, in 1976, 12 percent of the trees had large patches of dead cambium and 3 percent had thin foliage, whereas neither were found in 1971. More than twice as many trees in 1976 than in 1971 had defective form including spiked and forked tops. And 15 percent of the trees were attacked by bark beetles (indicating poor vigor) in 1976, whereas bark beetle attacks were negligible in 1971.

Failure of diameter growth to reach prefreeze rates after 4 years may have been the effect of causes other than the freeze. In 1976, precipitation at Weaverville was only 45 percent of normal. Increasing intertree competition probably contributed to a big drop in growth of trees spaced 9 by 9 feet. And finally, this hybrid stand may have passed the age when current annual diameter growth normally peaks. Annual basal area growth returned to prefreeze rates by the third year following the freeze.

Spacing Effects

Mortality and residual effects of the freeze on growth may have eliminated or overshadowed most of

the evidence of direct influence of spacing on growth. Nevertheless, because neither mortality nor damage severity changed the relation of spacing treatments to each other, a few observations are possible.

Spacing has influenced diameter growth more markedly than any other stand characteristic investigated (table 4). Annual means during both periods were from 0.28 inch (0.7 cm) for trees spaced 8 to 9 feet apart to 0.48 inch (1.2 cm) for trees spaced 14 to 22 feet apart. Differences were significant only between spacing extremes during the first 2 years and among all spacings during the third through fifth years.

No significant relationship was found between spacing and height growth. Trees in plots spaced at 22 by 22 feet during the second period tended, however, to grow less in height than did trees in plots at narrower spacings.

Stand growth in basal area and net volume (gross volume less mortality) was negligible in plots at the two wider spacings during the first two years after thinning because mortality was high. Although trees spaced 8 by 8 feet grew significantly more basal area and volume during the first 2 years than trees at wider spacings, growth was still only two-thirds of that possible without mortality.

During the second growth period (3 to 5 years after thinning) no trees died and plot growth tended to be related more strongly to spacing. Basal area growth was significantly different only between spacing extremes. The relationship between net volume growth and spacing was not significant, although a strong trend towards greater growth of both measures in plots with trees at narrower spacings was apparent.

Table 4—Mean annual change in stand characteristics 2 years and 3 to 5 years after thinning knobcone $\times$ Monterey pine saplings¹

Time period and spacing treatment (ft)	Mean annual change				Mortality		
	Avg. d.b.h.	Avg. height	Basal area	Net volume	Trees killed	Basal area	Volume
	<i>Inches</i>	<i>Feet</i>	<i>Ft²/acre</i>	<i>Ft³/acre</i>	<i>No./acre</i>	<i>Ft²/acre</i>	<i>Ft³/acre</i>
First 2 years after thinning:							
8 by 8	0.30	1.5	3.2	52	58	2.0	28
12 by 12	0.34	1.8	0.3	11	55	2.4	29
16 by 16	0.48	1.9	-0.3	2	42	1.8	23
Third through fifth years after thinning:							
9 by 9	0.26	1.2	5.4	67	0	0	0
14 by 14	0.35	1.2	3.3	41	0	0	0
22 by 22	0.48	0.9	2.1	24	0	0	0

¹ Data from two plots for each spacing treatment are combined. Means not significantly different are bracketed ($p \leq 0.05$).

CONCLUSIONS

Damage and mortality from freezing must be considered in the management of knobcone $\times$ Monterey pine plantations if temperatures as low as -10°F (-23°C) can be expected at the planting site. Even during a rotation as short as 30 years, weather records indicate that the chance of a hard freeze is about 75 percent. A cold wave of similar intensity and duration hit this area in 1932.

Precommercial thinning often does not pay in management of plantations on short rotations for roundwood (Bennett 1971). Thinning probably would not have been necessary or desirable here if trees had been planted to a 6- or 8-foot spacing. Freeze mortality would have provided adequate thinning, if it were needed.

Certainly, thinning plots to 12- and 16-foot spacings followed by severe mortality left so few trees per acre that yields will suffer within the short rotation suitable for this hybrid. Mortality was proportionally less, however, after thinning to an 8-foot spacing. The approximate 9-foot spacing which resulted should provide adequate stocking even through another killing freeze.

Unlike growth loss from mortality, the growth loss of trees surviving the freeze cannot be offset by closer spacing. Winter temperatures at this location probably

are too cold for maximum yields of the hybrid. Minimum temperatures at similar marginal timber sites at lower elevations, especially those facing California's Central Valley, were not lethal in December 1972. Whiskeytown Reservoir and Shasta Dam reported minimums of 16°F (-9°C) and 20°F (-7°C), respectively. Both temperatures are well above the 11.8°F (-11.2°C) which Stockwell and Righter (1946) found did not injure 8-year-old knobcone $\times$ Monterey pine hybrids. In spite of occasional freeze damage at this elevation (3200 feet), plantations of closely spaced knobcone $\times$ Monterey pine producing less than maximum yields should be successful. Its diameter growth is so rapid that even most freeze-weakened trees are growing faster than ponderosa pine of the same age planted nearby.

Possibly, greater freeze resistance can be bred into the hybrid. Damage from the December 1972 freeze to Monterey pine along California's north coast showed high variability which Hood (1975) attributed to the species' genetic diversity. Susceptibility to freeze damage may vary widely in knobcone pine, also. Three-year growth of hybrids produced from knobcone pine parents from the northern end of their range was reported by Griffin and Conkle (1967). Their performance following the 1972 freeze should be evaluated.

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Oliver, William W.

1979. **Growth and mortality of thinned knobcone × Monterey pine saplings affected by engraver beetles and a hard freeze.** Res. Paper PSW-139, 9 p., illus., Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Mortality and diameter growth loss were severe on study plots in a thinned plantation of 9-year-old trees. California five-spined engravers killed 15 percent of the trees and a hard freeze killed 20 percent of the survivors. Mortality was higher and subsequent diameter growth was lower in trees with most of their needles freeze-killed than in trees less severely damaged. In spite of occasional freeze damage at 3200 feet elevation, plantations of the hybrid can be successful if trees are closely spaced to provide for freeze mortality.

Retrieval Terms: *Pinus attenuata* × *Pinus radiata*, growth, mortality, thinning, *Ips paracinctus*, freeze damage.

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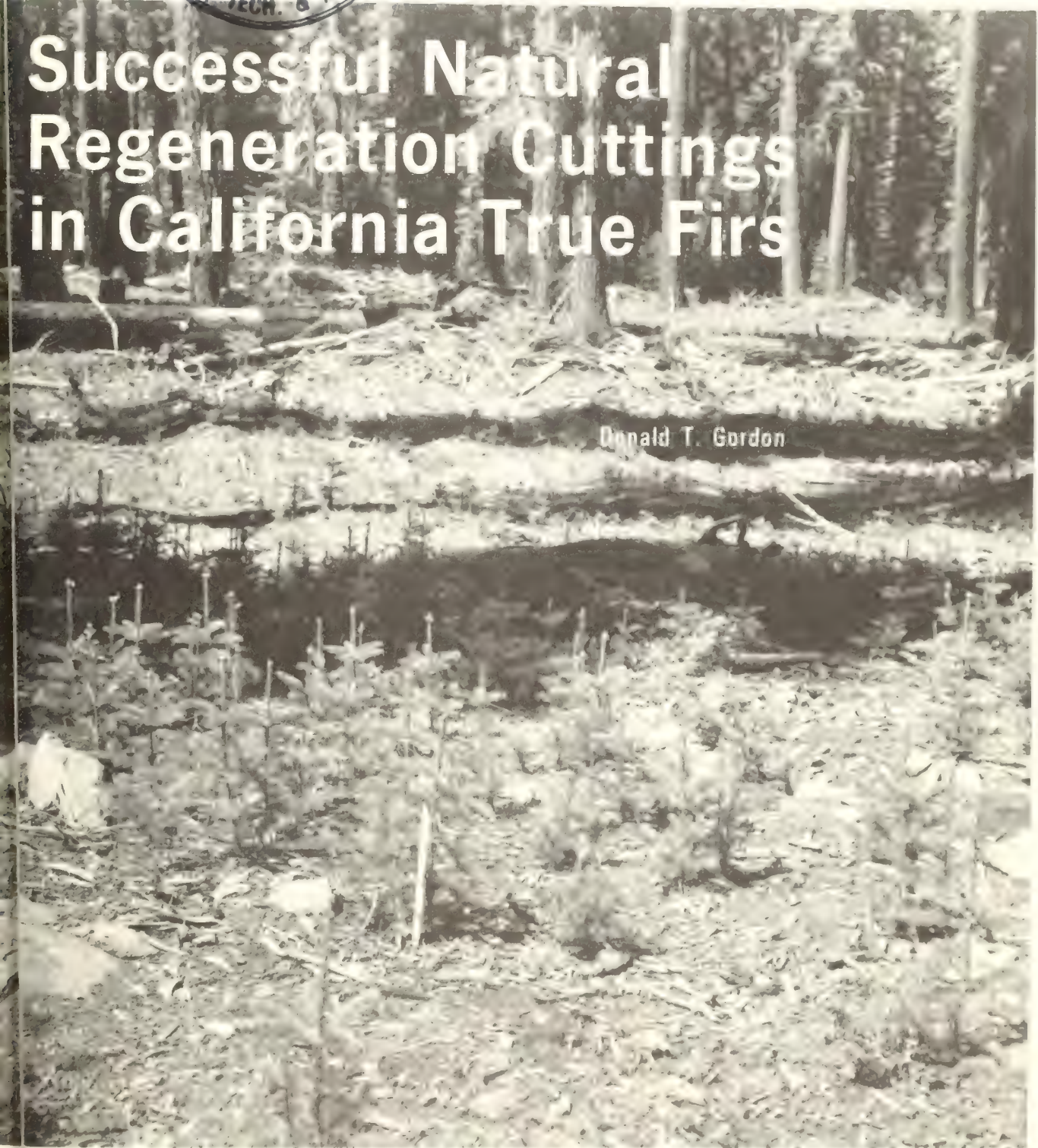
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PACIFIC SOUTHWEST Forest and Range Experiment Station

Successful Natural Regeneration Cuttings in California True Firs

Donald T. Gordon



The Author

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Successful natural regeneration cuttings in California true firs

Donald T. Gordon

CONTENTS

	<i>Page</i>
Introduction	1
Study Area	2
Methods	2
Seedling Establishment Study	2
Seed Traps	4
Tree Damage Sampling	4
Special Cutting Trials	5
Results	6
Seeds and Seedlings	6
Damage to Residual Stands	11
Discussion	12
Conclusions	14
Literature Cited	14

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IN BRIEF...

Gordon, Donald T.

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Retrieval Terms: cutting methods; slash disposal; seedbed preparation; damage; seedling stocking; seed; white fir; red fir; Swain Mountain Experimental Forest; natural regeneration.

Studies and observations reported here are partly extensions of previous work begun in 1958-60, and partly new trials. In the earlier work, regeneration was studied in clearcuttings 3 and 5 chains wide, and 13 to 40 chains long, in overmature mixed white and red fir stands. Damage in residual stands surrounding the cut areas was also studied. Results indicated that natural regeneration levels were high, but could have been fortuitously so. Reflection on results led to speculation that they might have been due to a beneficial combination of factors such as timing of logging and seed crops, and a relatively slow rate of development of low forms of vegetation (potentially competitive with fir seedlings). Therefore, new cuttings reported here were designed to surmount any combination of "average worst" conditions and whatever sequence of events occurred, so as to get a minimum of 30 percent of milacres stocked with fir seedlings within 3 years after cutting. Damage and mortality among residual old-growth trees again were monitored.

Ninety-nine cutting areas, prepared in 1970-72, formed the data-collection base for the regeneration studies. The cuttings at Swain Mountain Experimental Forest in northeastern California (also the location of earlier experiments), were mainly replications of these three groups:

Clearcut strips 1, 2 and 3 chains wide (20, 40, 60 m)

Clearcut squares 2 by 2, 3 by 3, and 4 by 4 chains

Seed tree cuttings, leaving 10, 20 and 30 largest and "best" trees per acre (25, 50, 75 per ha)

In addition, a group of 2-chain-diameter clearcuts and a series of parallel strips 2 chains wide were installed. Also, some of the strips 3 and 5 chains wide, cut in 1958-60, were widened 2 chains to windward (southwest) and 1 chain toward the northeast, simulating a possible follow-up practice where an even-aged stand covers a large acreage. A few areas approximating uneven-aged stand structure were cut so that no trees more than 150 years old, approximately, were left; included were some small regeneration areas, probably none exceeding 0.2 acre (.05 ha).

Mineral soil seedbed was prepared wherever regeneration was sought. Tractors equipped with normal blades or rock rakes windrowed all organic material. Tractor operators were instructed particularly to keep piles of debris out of the central area of each unit where seed and seedling sampling was to be done.

A heavy seed crop fell in 1971, and light crops in 1973 and 1974. Nearly all regeneration areas became stocked with seedlings at much better rates than the minimum of 30 percent of milacres stocked. Of the 99 areas included in the formal experiment, 87 percent exceeded the set minimum stocking. Eighty-three percent exceeded 50 percent.

Post-logging damage to residual old-growth was everywhere negligible. Least damage occurred in seed tree cuttings, showing that it is now possible to select trees which will produce abundant seed and yet not yield to normal wind storms.

Low vegetation developed slowly on regeneration areas; it appeared not to affect seedling survival.

The success of natural regeneration of white fir (*Abies concolor* [Gord. & Glend.] Lindl.) and red fir (*A. magnifica* A. Murr.) on logged areas has been found to be strongly related to the quantity of sound seed available and the presence of a mineral soil seedbed (Gordon 1970). Quantity of effective seed, in turn, was found to depend on periodic production of sound seed by a sufficient number of seed-producing trees; distance and direction of seedbed from seed source (considering wind currents only); and timing of snowfall—that is, whether seeds reached the seedbed before formation of a deep snowpack (seeds falling on permanent snowpack germinate in the spring but few become established in the soil).

Early research at Swain Mountain Experimental Forest, in northeastern California, provided some quantitative information on these matters. There was good stocking of fir seedlings on 3- and 5-chain-wide (60- and 100-m) clearcut strips wherever sufficient mineral soil seedbed was exposed through site treatment. The fact that seedlings were seen to be most numerous near cutting edges, which were the seed source, suggested that narrow or small clearcuttings should regenerate better than wide ones. Reflection on reported and unreported observations, however, indicated that good results, especially on the wider strips, might have been due partially to coincidence. Possibly, timing of logging and site preparation in relation to seed crops, and general lack of early aggressiveness of low vegetation on study areas were most influential.

Most forest managers would encounter practical difficulties if they accumulated regeneration areas to be cut only during good seed years. A preferable method is to cut and treat regeneration areas when other harvest methods are being used nearby. In true fir stands, a medium-to-good seed crop could be expected within 3 or 4 years after cutting. But, occasionally, a relatively poor seed crop might present the best probability for regenerating an area before it was "lost" to unwanted competing vegetation. The regeneration strategy to be

followed should insure maximum advantage from any seed crop within the first few years after site preparation. Such advantage can be gained by providing enough good seed trees, located so as to disperse a relative abundance of seed on prepared seedbeds.

The design of the cutting is important. On the average, most fir seeds fall within 1 or 1½ chains (20 to 30 m) of the source. Clearcuttings therefore should not be wider than twice those distances. Seed tree or shelterwood cuttings should also be designed to provide sufficient seeds. Previous studies (Gordon 1970) confirm that clearcuttings not exceeding 3 chains (60 m) in width should produce abundant regeneration. Clues to required numbers of large trees to be left for the seed tree cutting method were provided by my study of an Eldorado National Forest red fir stand cut more than 15 years previously. There, 10 large seed trees per acre (25/ha) had provided good amounts of reproduction wherever soil surface was disturbed. Seed trapping also showed uniform seed distribution over such areas.¹

The studies of natural regeneration in red and white fir reported here were designed to explore (1) the relation of type and size of cutting to seedling stocking; (2) the relation of seed quantity and dispersal to stocking; and (3) the relation of type and size of cutting to tree damage. As criteria for stocking level, the seedling requirements under consideration as part of the California Forest Practices Act were used. Adequate stocking was judged as a minimum of 30 percent, based on the number of milacres stocked with one or more live seedlings. Stocking was evaluated annually for 3 years after cutting.

¹ Unpublished data on file, Pacific Southwest Forest and Range Experiment Station. Seed was sampled with 8.2 square-foot seed traps, 32 traps on each of two adjoining 1-acre areas. Mean seeds per trap for each of the two areas were 19.8 and 20.1, with standard errors of 0.90 and 1.13 seeds per trap. Mean seeds per trap for all sample lines ranged from 16.5 to 24.0.



Figure 1—Regeneration cuttings were placed in stand condition like that shown in the background: dense old-growth mixed white and red fir, lacking understory. (Swain Mountain Experimental Forest, California)

STUDY AREA

At the study location, Swain Mountain Experimental Forest, elevations range from 5700 to 7000 feet (1737 to 2134 m). Precipitation, which averages 40 to 50 inches (1020 to 1270 mm) a year, is mainly snow. Snow surveys during four winters found usual maximum snowpack depth to be about 8 feet (2.4 m); it was 14 feet (4.2 m) at some places during one winter. Summers are warm, and dry except for infrequent thundershowers. Soil is 3 to 8 feet (1 to 2.4 m) deep; it

is derived from vesicular andesite and contains varying amounts of rock. Site quality is mostly rated at II (Dunning 1942), and old dominant trees average 150 feet (45 m) tall. Board foot volume as great as 147,000 per acre has been measured in a dense old-growth stand. White fir and red fir are mixed in various proportions through much of the Experimental Forest, but red fir becomes the exclusive species near the top of Swain Mountain.

METHODS

The methods used are described here under three major headings corresponding to the study objectives. The main study sampled regeneration which became established on a variety of cuttings. In the complementary studies, seed quantity and dispersal were checked by means of seed traps, and tree damage in or near regeneration areas was monitored.

Seedling Establishment Study

All regeneration cuttings studied were placed in dense, old-growth, mixed white and red fir stands lacking advance reproduction (*fig. 1*).

Cutting Treatments

Replicated cutting treatments were as follows: clearcut strips 1, 2, and 3 chains (20, 40, 60 m) wide, all 6 chains (120 m) long; clearcuttings 2, 3, and 4 chains (40, 60, 80 m) square; and seed tree cuttings 6 chains (120 m) square which left levels of 10, 20, and 30 of the largest and best trees per acre (25, 50, 75/ha) as seed source.²

For convenience and reference, a series of three widths of cutting strips was termed a "strip set," the three sizes of clearcut squares, a "square set," and a series of different seed tree densities, a "seed tree set."

In all, 99 cutting areas were sampled for different parts of the studies. Restricted access prohibited cutting of equal numbers of like cutting sets in suitable stands in each of the 3 years of the timber sale—1970, 1971, and 1972. The 3-year sale duration was planned in order to sample seedling establishment in relation to seed crop occurrence and time since seedbed preparation. The sale contract specified that site preparation had to be completed on all of a season's logged area before October 15, the approximate time when seedfall begins.

All cutting areas were designed to attain the minimum stocking level—at least 30 percent of milacres with one or more fir seedlings. The sizes and shapes of cutting areas selected for trial in the seedling study were based on previous research findings and on estimates made from observations. A desire to use only the minimum amount of forested area to achieve study objectives was a strong consideration.

A previous report showed that most sound seed fell at less than 1½ chains (30 m) from its source (Gordon 1970). Therefore, length of all clearcut strips was established at 6 chains (120 m) so that the central 2 chains (40 m) of length would not be measurably affected by windborne seed from the ends. Seed tree cuttings were 6 chains square so that a central 2-chain-square sampling area would be free of influence of seed from trees beyond the edges of the cutting. The square clearcuttings were judged to be subject to influence of windborne seed from any direction. Sides were cut straight to provide well-defined edges from which to measure any effects within study areas; ordinarily, edges would be slightly irregular to favor good seed

trees, to minimize wind damage, and for pleasing appearance.

Because previous study showed that seed was dispersed mainly by southwest winds, most cuttings were oriented so that the long sides of strips, and any two sides of square clearcuts and square seed tree cuttings, were oriented northwest-southeast. Most strong storm winds in the area blow from the southwest, so the northwest-southeast orientation was judged helpful also to reduce susceptibility of trees just outside the cuttings to wind damage (Gordon 1973). A few cuttings were oriented in other directions for comparison.

The cutting units that made up the strip sets, square sets, and seed tree sets were placed near each other. An uncut strip of timber of 2 chains (40 m) minimum width was always left between units to minimize possible differences attributable to seed source. The sets were installed on aspects ranging clockwise from west through southeast. (South and southwest aspects on Swain Mountain were covered with brush.)

In a supplemental test, some seed tree cutting units, including some on south aspects, were installed on several other National Forests in the California Region.

Seed Tree Criteria

Schumacher's (1928) stand tables for red fir show about 60 trees per acre (150/ha) larger than 24 inches (60 cm) d.b.h. at age 160 on most sites, so the residual seed trees constituted from one-sixth to one-half of the largest trees. Criteria for ideal trees to be left in the seed tree cuttings were (a) sound, pointed tops (fir seed is borne only near tops), (b) absence of evidence of mechanical defect such as rot, "dwarfmistletoe cankers," and fire scars, (c) probable strong root development (as indicated by relatively large amount of area occupied by tree), (d) position as dominant or codominant tree in overstory, and (e) spacing needs.

Sampling Areas

Stocking was evaluated on milacre plots in selected sampling areas. Stocking rate was based on the number of plots with one or more live seedlings, and on seedling counts on a limited number of plots.

The known seed dispersal patterns suggested that stocking rates and seedling counts would be at lowest levels near centers of cutting units. Sampling areas were therefore placed at centers of cutting units as follows: strips—½ by 2 chains (10 by 40 m);

² "Seed tree" is used as a phrase of convenience. Thirty trees per acre might be called "shelterwood."

squares—1 by 1 chain (20 by 20 m); seed tree—2 by 2 chains (40 by 40 m). Seedling stocking on portions of cutting units between cutting edges and central sampling areas was determined at the end of the study. A system of temporary milacres was used to gather stocking data for comparison with that obtained in the central sampling area.

Because mineral soil was already known to be the best seedbed, specifications called for this on at least 75 percent of the surface of any milacre plot to be installed. Therefore equipment operators were directed by Forest Service personnel to remove as much organic material as they could from central sampling areas. Piled or windrowed slash was placed mostly between the central sampling area and uncut edges. Straight bulldozer blades and brush rakes were both tried on this work, and we found little difference in results.

In the year after logging and site preparation, 30 permanent square milacre plots were installed randomly in each central sampling zone. Milacres were marked with two 6-inch spikes driven into the soil; locations were mapped and numbered. Wherever a random milacre could not be placed because of rock, stump, or other obstruction, a predetermined choice sequence eliminated bias in an alternate placement.

All milacres were examined in the fall of each year to determine stocking—the presence or absence of post-logging seedlings. In addition, two full sets of 1970 cuttings were selected at random for counts of seedlings. Every third milacre plot on those areas (180 plots in all) was specified for the seedling counts. Seedlings were counted separately by age classes in spring or fall, from spring 1972 to fall 1975.

At the first examination, descriptive data for each cutting unit were recorded as follows: aspect, slope percent, orientation of sides, year cut, and seed source rating. The seed source rating was intended to estimate potential red and white fir seedfall. For seed tree cuttings, the rating consisted of percentages of white fir and red fir seed trees counted. For the clearcuttings, it was an index number derived from examination of timber within 1 chain (20 m) of cutting edges, and considering age class, density of stocking, and size of any gaps in cutting edges. Also recorded for clearcuttings was the tree species (white or red fir) dominating all sides, and the southwest side only.

Seed Traps

Seed crops developing in 1971, 1973, and 1974 were sampled, using traps 10 by 14 inches (25 by 35 cm), designed to resist effects of snowpack loads.

Seedfall data were derived primarily from 10 seed traps placed centrally in each of certain cutting areas used in the seedling study. Traps were placed immediately adjacent to seedling-sampling milacres, beginning with milacre 2 and continuing with every third milacre to number 29. Traps were placed adjacent to all milacres on which seedlings were counted (two complete sets each of strip, square, and seed tree cuttings). Seed traps were also placed next to milacres on additional complete cutting sets as follows: strips—2 sets, square—1 set, seed tree—1 set. Where more than one choice of set was possible, selection was made randomly. In all, 10 complete sets of 3 cutting areas each were sampled with 300 traps.

Material in seed traps was bagged soon after snowmelt in the spring following a seed crop. Number of sound seeds per trap, as determined by cutting test, was the only statistic recorded.

A limited supplemental sample of seedfall was obtained between uncut edges and the central sampling zone of a few cutting areas. A complete set of cuttings, except for a 2- by 2-chain square, were sampled this way by from 6 to 16 traps, depending on size of areas (total 96 traps). This small sample served as a simple check on the assumption that seedfall within a central sampling zone would be less than at locations nearer to cutting edges.

Tree Damage Sampling

A previous study (Gordon 1973) determined amount and kind of damage to trees 4 inches (10 cm) d.b.h. and larger around some true fir clearcuttings. The study also allowed inferential determination of seed tree characteristics that might indicate low susceptibility to damage before natural regeneration is established.

Accordingly, the present study sought possible significant differences in tree mortality or damage to merchantable stems (11.6 in [29.5 cm] d.b.h. minimum) at these locations:

Adjacent to several sizes of small clearcuttings

Within seed tree cuttings having different numbers of seed trees

In undisturbed stands at some distance from any cutting

Around clearcuttings, the sample area extended one chain (20 m) from cut edges into uncut timber, at all sides of the areas. Within seed tree cuttings, and within uncut "control" areas in dense old stands, all trees became part of the potential sample.

Sample area locations and dimensions were as follows:

● *Adjacent to clearcut strips*

Two complete sets (six in all), giving 9.6 acres (3.88 ha)

Five additional 2-chain-wide (40-m) strips oriented other than northwest-southeast, giving 8.0 acres (3.24 ha)

17.6 acres (7.12 ha) total area

● *Adjacent to clearcut squares*

Two complete sets (six)

A 3- by 3-chain (60- by 60-m) and a 4- by 4-chain (80- by 80-m) cutting area

10.0 acres (4.05 ha) total area

● *Within seed tree cuttings*

Two complete sets (six)

21.6 acres (8.74 ha) total area, with theoretical total of 432 trees

● *Within uncut "control" areas*

Six areas with 1.6 acres each

Total 9.6 acres (3.88 ha).

All but two sample areas were located on 1970 cuttings in order to allow five winters of record.

After snowmelt in the spring, a cursory examination of the Experimental Forest was to be made to determine relative level of over-winter tree damage. If damage appeared to be normal, data would be collected in the fall (and this is what always occurred). Otherwise, data were to be collected in early summer so that salvage operations could begin. Damaged trees tallied in the study were sprayed with paint to prevent their being counted more than once.

In the field, for each dead or damaged tree, these data were recorded: species; direction of fall of whole or partial trees; d.b.h.; crown class; whether tree was live or dead; probable time of death or damage; whether tree was part of a damaged group or a single; whether tree was damaged directly or indirectly by wind; whether wind-damaged tree was down, leaning, hung up, broken, or struck by another tree; insect damage (by species, where possible); snow damage; other damage. Contributory causes of death or damage recorded were: root rot; bole rot; fire scar; shallow or wet soil; live or rotten bayonet tops; dwarfmistletoe; logging damage; snow; "twinning" (trees occurring in close proximity, often with resultant opposing fire scars and rot, lean, or incompletely developed root systems). The compass direction perpendicular to the side of a clearcutting at which damage occurred was also recorded.

Special Cutting Trials

Trials of a few additional cutting systems were installed during the 1970-72 timber sale period. In one group of cuttings, some older clearcut strips, 3 and 5 chains wide, were widened by clearcutting 2 chains toward the southwest (windward) and 1 chain to northeast. The objective was to learn whether such cuttings would acquire adequate natural regeneration.

On another group of four cuttings, Duncan Dunning's "unit area control" silvicultural concept (Hallin 1951) was applied. The areas ranged from 14 to 42 acres (5.5 to 17 ha). All consisted of stands appearing to be relatively uneven-aged, or even-aged by small groups. Cutting objectives were to:

- Remove all trees more than about 150 years old
- Secure natural regeneration wherever small openings were created (rarely as large as 0.2 acre [0.08 ha])
- Release understory groups from the growth-suppressing effect of older overstory (usually scattered)
- Change some age class structures by means of improvement cuttings
- Salvage some trees having bole defects such as breaks and "dwarfmistletoe cankers"
- On two of the areas, selectively thin some of the smaller immature age class trees to reduce competition

The purpose of these four cuttings was to establish for future study some areas representing uneven-aged stand conditions.

In planning the cuttings, we hoped to find a cooperator interested in studying their immediate effects on snow deposition and melt, and the later effects of newly regenerated areas on the snow as trees grew progressively larger and were subjected to planned manipulation. For this reason, another small but significant category of "snow cuttings" was made, consisting of four parallel clearcut strips 2 chains wide, separated by 1.3 chains of uncut timber. The result was an area with 60 percent of the timber removed—a condition found elsewhere to be about optimum for water yield where trees were spaced randomly. Additionally, a series of eleven circular clearcuts, 2 chains in diameter, was established on 3-chain centers. This simulated a "honeycomb" cutting—a concept attracting interest since the earliest snow surveys (Church 1933).

RESULTS

The main objective of these natural regeneration cuttings—achieving better than 30 percent of milacres stocked within 3 years after cutting—was realized on 87 percent of the 99 cutting areas in the seedling study, and 83 percent were stocked at a rate of 50 percent or greater.

Principal events affecting studies are shown here:

Event:	1970	1971	1972	1973	1974	1975
Summer cutting and site preparation	x	x	x			
Fall seed crop		x		x	x	
Spring seedling establishment			x		x	x
Fall rating of seedling stocking			x	x	x	x
End of study						x

The 1971 red fir seed crop was much heavier than the white fir crop of 1973 and the red fir crop of 1974, and provided abundant seedlings. But an encouraging result of the regeneration cuttings was that the lighter seed crops of 1973 and 1974 produced good stocking on unstocked areas, or increased stocking on areas already stocked well.

Logging the seed tree cuttings and small clearcuttings turned out to be easier than expected. Methods of slash disposal and site preparation were chosen to facilitate installation of studies reported here. The main objective—to ensure a high proportion of mineral soil seedbed—was achieved.

Results indicated, however, that ordinarily problems of slash disposal make regeneration site preparation difficult in true fir cuttings, especially seed tree cuttings. The number and large size of pieces of currently valueless cull material; dead material existing before logging; the presence of obstructions to bulldozer operation, such as stumps and living trees; and the resistance of green (wet) fir wood to burning for a year or more after logging—all these factors may affect the time required to do the job, its cost, and the appearance of the site. Additionally, large cull logs may obstruct seed tree removal at a later date.

Seeds and Seedlings

Seedfall

The seedfall sampling system was designed to give conservative results, for I assumed that fewer seeds fall near centers of cutting areas than along the edges. This

assumption seems valid. In the 27 samples (9 cuttings, 3 seed years), seed counts at centers of areas were less than near edges in 17, equal in 2, and greater in 8; there was no apparent relationship to type of cutting. As will be shown, seedfall sampling was adequate to reveal such a relationship if it had existed.

No data are available for testing to indicate whether or not any of the regeneration cuttings might have stimulated or depressed cone production. Levels of cone production during the study are suggested by data drawn from a long-term study at Swain Mountain:

Year:	White fir cones ¹	Red fir cones ¹
1970	308	0
1971	2291	1510
1972	0	1
1973	1152	13
1974	6	688

¹ Visible cones counted; no adjustment for nonvisible cones.

Seed crop size is ordinarily useful information for interpreting potential seedling crops. Red fir cone production was high throughout the Experimental Forest in 1971, and large numbers of red fir seedlings appeared in 1972. The 1974 red fir cone crop was good enough to improve the average seedling stocking rate of many cutting areas, a few of them substantially. In addition, full milacre stocking was reached on a few cutting areas in 1975, reversing the previous condition, in which plots were nearly unstocked. The white fir cone crop of 1973 resulted in some seedling establishment. However, two examples of contrary white fir cone crop indications were noted at Swain Mountain. First, no white fir seedlings were found during seedling plot establishment in 1971, following the small cone crop of 1970. Then, in 1971, the northeastern section of the Experimental Forest (which included the source of data for the tabulation) was the only part showing scattered evidence of a heavy white fir cone crop, but few resulting white fir seedlings were found there in 1972. These examples strongly indicate that the cone counting study did not necessarily represent average cone production of white fir on the Forest as a whole.

Sampling with seed traps indicated that seedfall on specific kinds of areas may vary tenfold or twentyfold between years of heavy crops and recognizable lighter crops (*table 1*). In a heavy crop year, sound red fir seeds fell on regeneration areas at rates of 300,000 to

Table 1—Estimate of sound seed falling near centers of cutting areas in three different years, Swain Mountain Experimental Forest

Cutting treatment	Seeds, by seedfall year		
	1971	1973	1974
	— Thousand/acre		
Clearcut strip:			
1 chain wide	704	47	55
2 chains wide	721	24	37
3 chains wide	566	21	19
Clearcut square:			
2 × 2 chains	1620	31	54
3 × 3 chains	1311	30	27
4 × 4 chains	1412	29	27
Seed tree cutting:			
10 trees/acre left	460	19	60
20 trees/acre left	439	30	30
30 trees/acre left	637	63	52
Average	541	33	40

¹ Based on two replications rather than three.

700,000 per acre (740,000 to 1,730,000/ha). These data agree closely with those from the previous study (Gordon 1970) at Swain Mountain.

For each of the 3 years studied, there was no statistically significant difference in seedfall between three clearcut strip widths, three clearcut square sizes, or the three levels of leave trees in seed tree cuttings. Neither were there any significant differences between the major cutting treatments—strip, square, and seed tree.

Seedling Establishment

In 40 of the 99 cutting areas in this study, the seed source for regeneration was predominantly white fir. In an earlier study (Gordon 1970), white fir trees were found to produce more sound seeds than red fir. Yet, established seedlings on the wider cutting areas of that study, as well as on those of the current study, are mostly red fir. On the older cuttings there is some observed but unmeasured tendency for white fir to become established in the shade of other young trees and brush. Schubert (1956) and Stark (1965) also reported this trait of white fir for regeneration openings in Sierra Nevada mixed conifer stands.

Seedling survival trends were 21 percent for red fir after 4 years, and 23 percent for white fir after 2 years. In a previous study, white fir survival after 2 years in 3- and 5-chain wide strips was 15 percent, and in a 1¼-chain wide opening it was 36 percent (Gordon 1970).

The abundance of established seedlings is illustrated by a frequency distribution of milacres by number of seedlings per milacre at final examination (1975) of 18 cutting areas (*fig. 2*). It is interesting that 17 of the 19 milacres with no seedlings were on only two cutting areas—one 3 by 3 chains, one 4 by 4 chains—the two most poorly stocked areas in the study.

Trends of seedling establishment from three seed crops on some randomly paired cutting areas (*table 2*) are consistent with previous research results on the influence of seed dispersal, shade, and other factors (Gordon 1970).

Seedlings were most abundant on the narrowest clearcuttings, both initially and at the last examination. Seed tree cuttings had most seedlings where most seed trees were left (*fig. 3*). Further evidence of the effectiveness of small or narrow regeneration areas is the flush of new seedlings observed at Swain Mountain in road rights-of-way, in selection cuttings, and in eleven 2-chain-diameter clear-cuttings.

One-year-old seedlings made up about a fourth to a half of all seedlings observed at different areas in 1975. Although some of those will die soon, seedling numbers for all ages are high on the nine kinds of cutting areas: about 2000 seedlings per acre, from 1 to 4 years old, is the minimum (on the 4- by 4-chain areas in 1975, *table 2*). Even this minimum undoubtedly will exceed present requirements of the State of California Forest Practice Rules for completely regenerated areas—300 established seedlings per acre (741/ha) 5 years after cutting.

Survival of seedlings was comparable to that in four samples previously reported (Gordon 1970) to give results in the range of 10 to 50 percent after three growing seasons.

Stocking Factors

Stocking of milacres by one or more fir seedlings in 1975 was analyzed to determine what variables affected stocking rates significantly. Variables tested were (a) the 3 major and 9 minor cutting treatments, (b) year of cutting, (c) interactions of treatments and years, (d) "seed source index" (which attempted to quantify the "goodness" of seed source), and (e) species. A series of multiple regressions yielded means which were compared for difference by using F-tests at $\alpha = 0.05$. Through a process of elimination of least significant elements, only three variables survived in the most satisfactory model, which yielded a coefficient of determination (R^2) of 0.81. In that model, significant differences of means were found for (a)

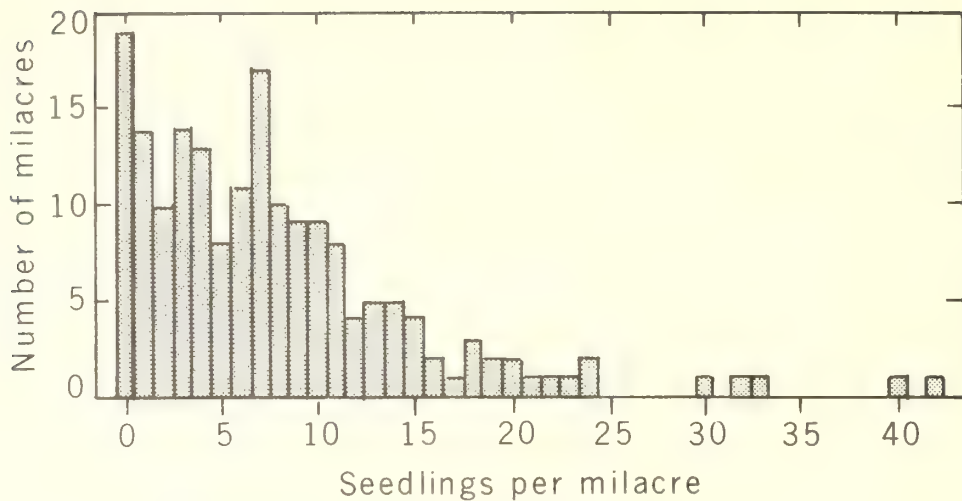


Figure 2—Seedling abundance at final examination of 18 cutting areas in 1975 is evident here from a frequency distribution of milacre plots by number of seedlings per plot. Total count was 1407 seedlings (any age) on 180 milacres. (Swain Mountain Experimental Forest, California)



Figure 3—Five-year-old red fir seedlings were abundant on an area where 30 large seed trees per acre were left. (Swain Mountain Experimental Forest, California)

Table 2—True fir seedlings, from three seed crops, observed on cutting areas,¹ Swain Mountain Experimental Forest, California

Time of observation	Seed crop year	Seed tree cuttings, leaving (trees/acre)			Clearcuttings					
					Strips			Squares		
		10	20	30	1 chain wide	2 chains wide	3 chains wide	2 by 2 chains	3 by 3 chains	4 by 4 chains
		Average seedlings per milacre								
1972, spring	1971	15.0	17.3	22.3	20.9	14.3	11.8	18.3	7.5	14.3
1974, fall	1971	3.1	6.1	8.3	6.4	2.8	2.2	4.0	0.8	0.8
1975, fall	1971	2.7	5.6	7.4	5.9	2.7	2.2	3.3	0.7	0.8
1974, spring	1973	3.5	2.9	16.4	3.4	0.2	4.9	3.7	3.7	2.3
1974, fall	1973	1.4	1.4	6.5	1.2	0	1.7	4.2	0.9	0.8
1975, fall	1973	0.5	1.0	5.6	0.8	0	0.5	0.7	0.4	0.3
1975, fall	1974	3.8	2.5	5.2	5.9	1.5	5.9	1.5	0.4	1.0
1975, fall	1971, 1973, 1974	7.0	9.1	18.1	12.6	4.2	8.6	5.5	3.1	2.1
Survival, percent ²										
After 4 years	1971	18	32	33	28	19	19	18	9	6
After 2 years	1973	14	34	34	24	0	10	19	11	13

¹ Data from two cuttings of each kind except, for strip 2 chains wide, one area only.

² For seed crop year 1971, based on 1975 fall count/1972 spring count; for seed crop year 1973, based on 1975 fall count/1974 spring count.

major treatments, (b) year of cutting, and (c) interactions of treatments and years.

The differences between the means for cutting treatment (table 3) are apparently real. Differences between years occurred principally because the 1970 and 1971 cuttings both received the abundant seedfall of 1971, as well as the lighter seed crops of 1973 and 1974. But the 1972 cuttings received only the two lighter seed crops. In reality, then, the effect of year of cutting chiefly reflects timing of seed crops.

An alternative interpretation is that for each major cutting treatment, each of the three minor treatments had about equal influence on the mean level of stocking. The relatively poor showing of clearcut squares is unexplainable when compared with relatively good stocking on other small openings of the same ages at Swain Mountain.

The relation of number of seedlings to number of seed was examined but with little success. Data analyzed were seed caught in traps immediately adjacent to milacres on which seedlings were counted. Seedlings in early spring of 1972 and 1974 were com-

pared with seedfall of 1971 (heavy) and 1973 (light), respectively. Regression lines plotted through the two sets of data (fig. 4) show only in a general way what we would normally suspect: that seedling numbers increase as seedfall increases. Large sampling error in seed numbers prevents "error band" confidence statements, so the trends shown must be regarded with reservation. An interesting comparison is that for a year of heavy seedfall, seedling numbers doubled with

Table 3—Milacre stocking with fir seedlings of any age in 1975, by major cutting treatment and year of cutting, Swain Mountain Experimental Forest, California

Cutting treatment	Stocking by year of cutting			
	1970	1971	1972	Mean
Percent				
Clearcut squares	65	95	25	53
Clearcut strips	84	67	53	68
Seed tree	98	99	73	95
Mean	86	92	42	

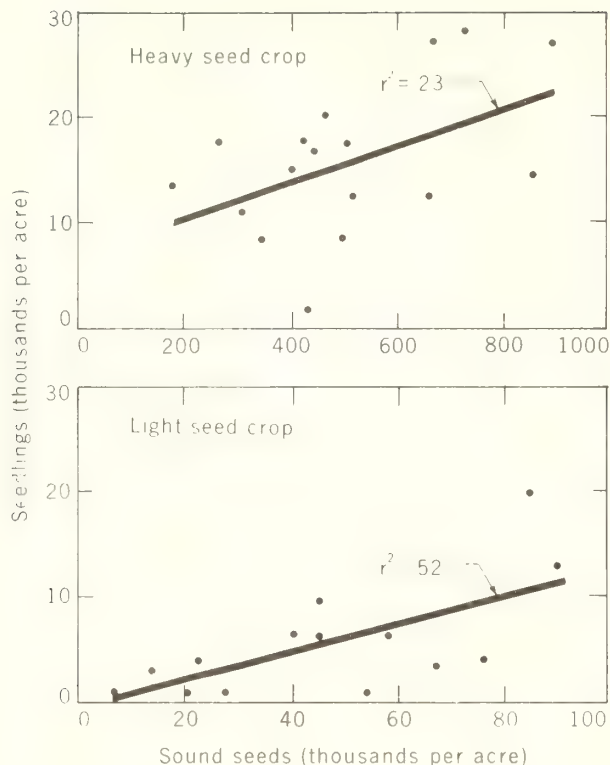


Figure 4—Seedlings counted shortly after germination are obviously related to seeds trapped after heavy and light seed crops. Notice that crops are graphed at different scales because of seed numbers; the slopes actually are not parallel. (Swain Mountain Experimental Forest, California)

a fourfold increase in seed, whereas, in a year of scarcity, seedling numbers doubled with only a twofold increase in seed. Such a difference could be due to the sum of influences of several factors.

Seed tree cuttings with the same numbers of residual trees as in this study were planned on several National Forests, for comparison with Swain Mountain results. Only two installations were prepared in time to be included in comments here. But in the fall of 1976 I observed that natural regeneration was abundant wherever mineral soil was exposed in red fir cuttings on south aspects on the Pacific Ranger District of the Eldorado National Forest, and on generally eastern aspects on the Downieville Ranger District of the Tahoe National Forest. Results on those areas indicate that regeneration success on seed tree cuttings is attainable at different locations in the red fir forest type.

Heights of 5-Year-Old Red Fir Seedlings

In 1976, a small supplemental study of 5-year-old red fir seedlings showed average total height to be 8.6

inches (21.8 cm). The sample consisted of 30 seedlings randomly selected in the usual sampling zone in each of 18 paired cutting areas, representing the 9 replicated cutting treatments. Analysis of variance indicated no significant height differences between treatments (each pair of cuttings was considered a treatment). Neither were there any significant differences between means of the major cutting groups: strip, square, and seed tree.

Though 5-year trends suggest that seedling growth was unaffected by cutting method, the fact should be noted that fir seedlings normally develop very slowly the first 3 or 4 years of their lives before height growth accelerates. Thus, seedling heights at 5 years do not indicate the competitive effect of residual trees. Even so, seedling heights did decrease slightly with nearness to seed trees—as noted previously for ponderosa pine (Teeguarden and Gordon 1959, McDonald 1976), a species with rapid early growth. Seed trees should be removed early where fast rates of seedling height growth are important.

Special Cuttings

In the four areas cut to create uneven-aged conditions, stands are now in an overall younger and more vigorous condition than before, and small openings are nicely regenerated. Although no studies are installed there, these areas have had considerable use as demonstration units for stand manipulation.

The widening of older strip clearcuts worked out well. In all four instances, the area that was cut 2 chains into the windward edge regenerated better than the 1-chain-wide strip to leeward. Seedling stocking in 1976, measured by randomly located milacres, ranged from 42 to 66 percent of milacres at the windward locations, 20 to 56 percent at the leeward. Because all of these areas were cut in 1972, they did not benefit from the heavy seed crop of 1971.

Two areas, the so-called “snow cuttings” installed in 1971, benefited from heavy seedfall. All 4 strips and 11 circular openings are observed to be covered with reproduction. The “honeycomb” area received little wind damage, but the parallel strips did receive some; it was relatively light, but, experience suggests that considerable damage could have occurred if strong winds had hit the area. Such cuttings in unmanaged old-growth expose to wind trees known to be most susceptible to damage—mainly trees of intermediate and suppressed crown classes, close-growing pairs (which have imperfectly developed root systems, and frequently, opposing fire scars with accompanying

bole rot), and trees with mechanically defective boles (those with fungal brackets, severe fire scars, and dwarfmistletoe cankers). Opportunities for study of snow on the several kinds of cuttings on the Experimental Forest will remain for many years.

Damage to Residual Stands

The damage study monitored events within one chain (20 m) of edges of 19 clearcuts, within 6 seed tree cuttings, and within 6 uncut "control" plots.

The most informative results of the damage study were these:

1. Seed tree cuttings were damaged only lightly (table 4), and least of any kinds of natural regeneration cuttings tried—showing that we can successfully choose true firs which are especially resistant to damage.

2. Uncut stands adjacent to clearcut narrow strips and small squares also were damaged only lightly. There was no evidence of unusually severe damage during the study; the annual range in damage adjacent to clearcuts was about the same as that around slightly larger clearcuts in an earlier study (Gordon 1973), during years without unusual storm damage.

3. A small trial of nonstandard clearcut strip orientation produced these results:

a. Two-chain-wide strips oriented north-south and east-west did not show damage noticeably different from strips with "standard" northwest-southeast orientation.

b. A single 2-chain-wide strip oriented with its long axis southwest-northeast (parallel with the usual storm winds) illustrates the care needed to minimize potential damage from wind. The northeast end and southeast side of this area were damaged moderately by a southwest or west wind in the first winter after cutting; here, the number of trees and volume lost per acre of uncut adjacent area was more than double that of any other kind of cutting. Though based on a single instance, this exemplifies the principle that cuttings should not create narrow or restricted corridors for normal storm winds to pour into.

Two-thirds of damaged trees were red fir, one-third white fir. This approximates the proportions of both species in the stands cut. At the times tree damage was recorded, 91 percent of trees were dead, 9 percent still alive. Buprestid and Scolytid beetles were listed as causal agents in the death of 54 percent of the trees. Wind damaged 43 percent of trees, of which one-third were windthrown and two-thirds broken. Three-

Table 4—Five-year mean total of dead and damaged trees, by cutting area type and unit of sampled area, Swain Mountain Experimental Forest, California

Cutting area type and size	Mean trees/acre	Mean volume	Mean basal area	Mean volume
		acre	acre	lineal chain
		Bd. ft.	Sq. ft.	Bd. ft.
Clearcut strips, oriented NW-SE:				
1 by 6 chains (2)	1.43	571	3.35	571
2 by 6 chains (1)	.62	94	.87	94
3 by 6 chains (3)	2.22	4,331	14.72	4,331
Mean (6)	1.73	2,565	9.21	2,565
Clearcut strips, oriented as shown:				
2 by 6 chains, N-S (2)	2.19	2,666	10.37	2,666
2 by 6 chains, E-W (2)	.62	1,262	4.43	1,262
2 by 6 chains, SW-NE (1)	5.00	13,219	41.67	13,219
Mean (5)	2.12	4,215	14.26	4,215
Clearcut squares, oriented NW-SE:				
2 by 2 chains (2)	2.50	5,562	18.56	5,562
3 by 3 chains (3)	.83	1,764	6.07	1,764
4 by 4 chains (3)	2.71	3,362	12.98	3,362
Mean (8)	2.00	3,139	11.38	3,139
All clearcuts, means:	1.94	3,246	11.45	3,246
Seed tree cuttings, leaving:				
10 trees/acre (2)	.14	169	.68	169
20 trees/acre (2)	.14	281	.98	281
30 trees/acre (2)	.42	1,104	3.66	1,104
Mean (6)	.23	518	1.77	518
Uncut plots (6)	1.77	2,683	9.71	2,683

¹ Number of replications shown in parentheses.
² Mean volume per lineal chain of cutting edge, clearcuts only.

fourths of the broken trees had bole rot, mostly affecting 70 to 90 percent of diameter at the break. Mycelial fans of *Armillaria mellea* were found beneath basal bark of only three damaged trees.

Distribution of damaged trees by crown class was as follows: dominant, 37 percent; codominant, 18 percent; intermediate, 20 percent; suppressed, 25 percent.

The diameter class distribution of damaged trees is compared with calculations based on Schumacher's

(1928) red fir stand table for all trees, site 50 feet at 50 years, age 160:

D.b.h., inches:	Damaged trees	Stand table values
	Percent	
12-20	30	24
21-30	24	38
31-40	26	29
41+	20	9

The distributions by crown class and diameter indicate that damage to residual trees, especially at cutting edges, was proportionately greater among smallest and largest trees. Some unknown amount of mortality could be attributed to normal “breakup” or “deterioration” within the old stands in which cut and uncut areas were placed. At Swain Mountain, 147,000 board feet per acre has been measured in dense old growth stands, and I would estimate that mean volume of study areas would exceed 100,000 board feet per acre. The mean volume and basal area of damage per acre (table 4) indicate relatively little loss, and no noticeable trends attributable to area differences.

Only a fourth of all cutting areas were included in the damage study. It is appropriate to say, then, that areas sampled appear to represent well the events which occurred elsewhere.

Damage to Seedlings

Visible damage to seedlings by animals was not

great, and most of that seen was attributable to deer. Some seedlings which had been hedged more than once still appeared vigorous. On the average, browsed seedlings were about as tall as others. A few seedlings pulled up by cattle were seen lying on the ground, as if they had been pulled up accidentally with herbage and then spat out. Earth mounds of pocket gophers appeared on some cutting areas, but population of the animals never seemed great. Scarcely any damage could be assigned to them.

Details of early seedling mortality have been covered previously (Gordon 1970).

Development of Low Vegetation

During the period of study, low vegetation did not develop aggressively on most cutting areas. On the few areas where rapid revegetation occurred, sedge, small herbs, grasses, and the shrub *Ceanothus cordulatus* were the commonest plants. Development of such vegetation was mostly at locations with high water tables, such as flat benches and flat drainages. Such areas supported recognizable amounts and kinds of vegetation even beneath fairly dense old-growth tree canopies. Proliferation of that vegetation and other species occurred after logging, and after removing slash, litter, and small amounts of top soil during regeneration site preparation.

DISCUSSION

The regeneration trials reported here were designed principally for applications in even-aged management. Irregularly shaped strip or patch cuttings could be used to regenerate small isolated even-aged stands, or to regenerate larger stands by stages. Seed tree and shelterwood cuttings could be used to regenerate even-aged stands of any size. Judicious use of cutting system and pattern, and appropriate site preparation, should result in seedling stocking comparable to that reported here. Size of the regeneration units in this trial would also fit conveniently into some concepts of group selection cuttings for uneven-aged management.

No rigorous comparison can be made of seedling establishment of the two fir species on the kinds of regeneration cuttings tried at Swain Mountain. This is principally because there was no white fir seed crop that could compare in quantity with the red fir seed crop of 1971 falling on freshly prepared sites. I believe that most of the cuttings would favor establishment of red fir, which is better adapted silvically to fill those

niches, especially in the tension zone occupied by both species. White fir has been shown elsewhere to be damaged by late spring frosts, and to survive better under brush or trees than in unprotected locations (Schubert 1956). Low artificial side shade alone greatly increased survival of first year white fir seedlings at Swain Mountain (Gordon 1970). But there is no information affording a clear separation of the benefits to fir seedlings of overhead plant cover as it relates to reduction of damage either from excessive insolation or frost.

All of the strip, square, and seed tree cutting areas had straight sides. This condition was created to give clearly defined uncut edges for research purposes. Ordinarily, meandered edges would give a more pleasing appearance, and allow the forester to leave the most windfirm and “best” seed trees there. However, narrow islands and peninsulas of trees, and deeply cut pockets, should be avoided in order to reduce the potential for wind damage.

The success of reproduction on clearcut strip widening indicates the utility of that process. A similar process has been used in other places to enlarge irregular patches of established reproduction. Cutting "toward the sun" (south) can be helpful in establishing species which have early sensitivity to strong insolation.

The success of seed tree cuttings was particularly encouraging because of new seedling abundance and the near lack of wind damage. Two other advantages then become obvious: (a) implications of wind direction have no meaning with regard to seed dispersal or potential for damage, and (b) within a stand condition appropriate for a natural regeneration cutting, size or shape of area actually cut at one time is immaterial.

Where 10 or 20 seed trees per acre were left, appearance led most visitors to agree that those areas could properly be called "seed tree" cuttings. Thirty trees per acre seemed to fit a shelterwood classification best. At that level, about half the original trees were left, constituting a "residual" stand of perhaps 40 to 50 thousand board feet per acre. This obviously cast more shade than the heavier cuttings, but absolute or relative insolation at different kinds of cuttings was not measured. These shelterwood cuttings can appear as attractive as some uncut stands elsewhere, if slash has been eliminated.

A condition immediately obvious to observers is that where only 10 seed trees are left, only those which are phenotypically "best" are present. As progressively more trees are left, some poorer specimens must remain. The heaviest cutting, then, will leave trees which probably have best form, growth potential, and adaptation to local site factors.

Because of the abundance of seedlings on areas with 10 seed trees, I believe that cuttings down to 5 or 6 large residuals per acre should be tried. Where establishment of reproduction is the ruling purpose, only the necessary number of seed trees should be left. Then, when seed trees are removed, logging damage to seedlings will tend to be minimal.

After the third growing season, mortality of seedlings is much reduced. In an earlier study at Swain Mountain, red fir seedling survival at the end of the third, fourth, and fifth seasons was 54, 50, and 48 percent, based on number of seedlings present at end of the first season. When one or more increments of seedlings exceeds desired stocking standards for an area, seed trees should be cut, or cutting edges adjoining small clearcuts should be moved back (where stand structure allows), to remove the growth-retarding effect of large trees on seedlings in the first cutting area. An additional advantage can be gained by insuring removal of large trees at an early date: dwarf mistletoe

in the overstory seldom infects trees less than 3 feet (1 m) high (Scharpf 1969). Observation of reproduction on previous study areas indicates that this height is reached at about the tenth year, so seed trees should be removed between the third and tenth years after establishment of adequate reproduction.

Dwarf mistletoe infection is present in the few cutting areas described as having stand structure which is uneven-aged, or even-aged by small groups. There would seem to be no easy way to eliminate the infection from such areas. This may limit the applicability of selection systems, especially where infection rate is heavy, and tree growth remains slow due to competition in dense stands. But where silvicultural treatment allows trees to grow rapidly, dwarf mistletoe may have only an inconsequential effect (Scharpf and Parmeter 1976).

Because of past difficulty in securing adequate natural regeneration in true fir cuttings, research emphasis has been directed toward developing means for attaining it. One concern has been that too many seedlings may become established, and that stagnated thickets could develop. Observation of seedling, sapling, pole, and larger-sized tree groups still indicates that where there is no suppression by larger trees, rapid-growing dominant stems will develop to occupy available space. Suppression and mortality will occur among the poorer stems. At some stages of development, artificial thinning may increase or sustain growth rate of residual stems, but economic feasibility will also need study. Where deep snow packs are the rule, permanent stem bending or breaking by snow loading causes mortality, especially among weaker trees, but stocking by dominants usually remains satisfactory.

Heavy establishment of low forms of vegetation occurred on only a few cutting areas in these studies, and appeared not to have influenced fir seedling stocking. We cannot yet predict species or time of abundant development for most areas. There is certainty, however, that seeds of plants of lower successional stages lie stored in the forest floor for perhaps 300 years (Quick 1956). When a dense tree overstory is removed, conditions become favorable for germination of some or all of the stored seeds. A recent survey of 32 red fir cutting areas scattered widely in northern California (Gordon and Bowen 1978) indicated the diversity of vegetation to be expected, and that sampling vegetation on uncut areas results in poor predictions of plants of earlier successional stages which will appear on cut areas. Foresters must begin to build a body of empirical data for vegetation to be expected on specific areas.

Although low vegetation has not been aggressive on most cutting areas in these studies, plants are there, and will continue to develop—at least for a few years, until new young tree growth becomes so dense as to force them out again. That these low forms of vegetation may afford early and adverse competition with seedlings for soil moisture is one side of a coin. The other side is that these plants have a potential function as wildlife food and habitat, and as food for domestic livestock.

Slash disposal is closely related to regeneration results reported here. The most imperative need is for preparation of a loose mineral soil seedbed. Fire prevention needs are secondary. There is no necessity for a new young tree on every milacre of ground in a regeneration area. Therefore, some form of partial slash disposal is all that is required. Only enough

mineral soil need be exposed to ensure a predetermined minimum count and distribution of new seedlings. (How much is enough will become evident in practice.) Large cull logs should be eliminated wherever residual trees are to be cut and removed within a few years, merely to reduce tree breakage when next felling occurs. Fine slash might be removed to expose mineral soil in strips alternated with fines left in place. A bulldozer with angled blade could work along contours, meandering between stumps or live trees, throwing slash to one side. Almost continuous forward motion of the machine should make such a system inexpensive. Effective slash disposal and site preparation methods and costs probably differ considerably from those which will be necessary when forests are managed completely and intensively.

CONCLUSIONS

The natural regeneration studies at Swain Mountain Experimental Forest have shown that high rates of red fir seedling stocking and adequate rates for white fir can be achieved through proper use of several cutting systems and patterns. Silviculturists can use those tried systems with confidence. The two most basic consid-

erations in attaining regeneration goals are provision for (a) abundant seed supply and (b) a mineral soil seedbed. Effects of vegetation development and of damage from wind and other agents were negligible under the conditions created by the study.

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In stands of mixed white and red fir in northeastern California, cuttings for natural regeneration became well stocked with seedlings within 2 to 5 years after cutting. Seed tree and shelterwood cuttings, clearcut strips not more than 3 chains (60 m) wide, and patches not exceeding 4 chains (80 m) width were studied. Incidence of damage among residual trees in or adjacent to cuttings was negligible. Low vegetation developed slowly and did not appear to affect seedling survival.

Retrieval Terms: cutting methods; slash disposal; seedbed preparation; damage; seedling stocking; seed; white fir; red fir; Swain Mountain Experimental Forest; natural regeneration.

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